OPERATIONAL VARIABLES AND LIMITATIONS OF DIRECT FILTRATION

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OPERATIONAL VARIABLES AND LIMITATIONS

OF

DIRECT FILTRATION

by

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Water Technology Section

Pollution Control Branch

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SUMMARY

The direct filtration water treatment process is gaining acceptance throughout Ontario. This report outlines some of the operating limitations of direct filtration during periods of raw water turbidity in excess of 20 Ftu or diatom levels about 500 Asu/ml. The results of work carried out in a pilot plant basis to study the effect of other operating variables are also given.

Alum, ferric chloride and two cationic polyelectrolytes were studied to determine the performance of these primary coagulants through dual media of varying coal sizes. The importance of both time and intensity of mixing on the efficiency of the overall treatment process is discussed. Various turbidity levels were studied to determine polyelectrolyte filter aid requirements and in addition the effectiveness of monitoring interface turbidity as a control system was investigated.

The results indicated that direct filtration in many locations is an alternative to conventional treatment facilities. Raw water turbidity was an important factor when considering the direct filtration process. Short filter runs ($<$ 10 hrs) occurred when raw water turbidity required alum dosages in excess of 20 ppm at filtration rates of 4 Igpm/sq ft or greater.

The length of filter runs varied with diatom levels of 400 to 5,000 Asu/ml and with the filter coal size. Diatom levels from 1000 to 5000 Asu/ml required the use of coarse coal ($>$1.2 mm e.s.) to extend the length of the filter runs. However, the coarse coal required more frequent use of a

filter aid polymer than the coal sizes of 1.0 mm e.s. or less. In addition, more care on the part of the operator was required to ensure a good filter backwash.

With diatom levels less than 1000 Asu/ml and colour levels less than 5 Hazen, the optimum filter coal effective size was approximately 1.1 mm. This coal size handled raw water turbidity levels of 100^{+} Ftu on a short term basis. Under these conditions the use of a polymer filter aid was required to prevent filter breakthrough.

Both the flocculation mixing intensity and time affected the performance of the filter. The optimum mixing conditions were at a velocity gradient of 20 sec^{-1} lasting 10 minutes or less.

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1 INTRODUCTION

The direct filtration process differs from conventional sedimentation filtration systems in that the total solids, both natural and those which are added, must be stored in the filter.

The increase in design filtration rates to 4.0 Igpm/sq ft in Ontario in 1967, prompted the Research Branch of the Ontario Water Resources Com* to implement a programme to study the factors which influence filter performance at these higher filtration rates. At the time of the changes, it was felt that these rates would be achieved only with the proper pretreatment and sedimentation facilities. However, as a result of more recent developments, for example the use of polymers as filter aids and multi layer filter media, direct filtration proposals have already been received by the Ministry utilizing the 4.0 Igpm/sq ft maximum rate. As filtration rates following conventional pretreatment may conceivably approach 8.0 Igpm/sq ft [1,2] in the future, work to determine the maximum rates of direct filtration was undertaken to allow for a fair assessment of the advantages of each method of treatment.

Previous work [3] indicated that the single sand filter medium is inadequate for the direct filtration rates of 4-6 Igpm/sq ft now being studied. The limitation of the use of the available storage space within a single layer medium led to many operational difficulties. These included short filter runs due to the rapid clogging of the sand surface and early

* Since 1973 Ministry of the Environment
Pollution Control Branch
Water Technology Section

breakthrough. Fox and Metcalf indicate that upflow filtration by nature tends to keep the debris fluidized, and some may be carried with the filtrate [4]. At higher upflow filtration rates, the bed tends to partially fluidize although grid systems have kept this to a minimum. An alternative to these problems lay in the use of downflow multi media filters. These include dual media (anthracite and sand) and mixed media (anthracite, sand and garnet).

The direct filtration process has been in use in the Province of Ontario since 1964. The original plant is located in Metropolitan Toronto on Lake Ontario. In 1964, the plant was converted from drifting sand filters to direct filtration using alum as the coagulant.

Since 1964, at least four other newer plants have been constructed in Ontario. These include:

- the Lake Huron Water Supply System on Lake Huron,
- the Port Elgin Water Treatment Plant on Lake Huron,
- the Owen Sound Water Treatment Plant on Lake Huron,
- the Red Rock Water Treatment Plant on Lake Superior.

The raw water data and the design parameters for three of these plants are listed in Appendix A.

All of these plants were designed when the effluent turbidity objective in Ontario was 5 ppm, and prior to the time when high rate filtration was acceptable. In 1967, the

then Ontario Water Resources Commission (OWRC) revised the effluent turbidity standard to 1 Ftu [5].

The problems arising in these plants and the experimental tests carried out to overcome these problems are outlined in this report.

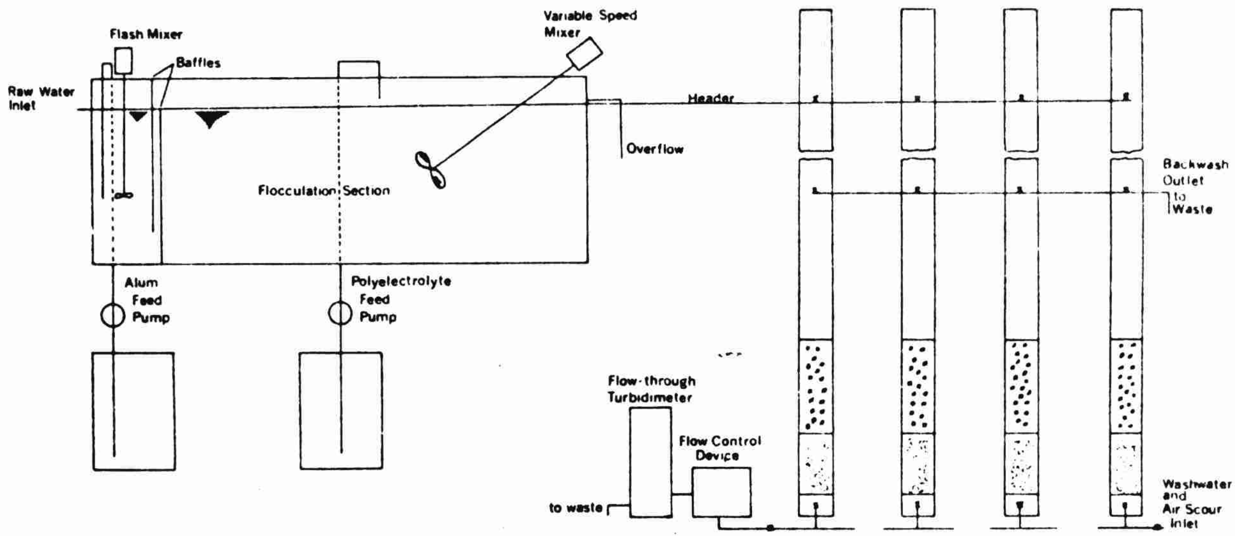
2. PILOT PLANT

2.1 Apparatus

A flow diagram of the pilot plant apparatus is shown in Figure 1.

FIGURE 1

PILOT FILTER PLANT LAYOUT



The raw water was pumped into the flash mix chamber where the primary coagulant was added. A 1/16 HP mixer supplied a flash mix velocity gradient near 500 sec^{-1} from one to two minutes for most tests. The coagulated water passed under and over two baffles to the slow mix section where flocculation took place with the aid of a 1/3 HP variable speed mixer. The flocculated water was then fed by gravity on to the filters. An overflow setting on the mixing box controlled the head of the filters.

The pilot columns consisted of four 6 inch diameter clear acrylic columns each ten feet high. The filter media was supported directly on Degremont gravelless underdrains. Piezometer taps allowed incremental headloss measurements to be determined for every three inches of media depths. Raw water turbidity as well as effluent turbidity was continuously monitored and sampled. The filtered water was pumped from below the underdrains with a constant flow determined by a needle valve setting throughout the duration of the run. All filter runs were terminated at 8 feet of headloss or when breakthrough occurred. Breakthrough was considered to be taking place when the effluent turbidity had become a function of time and had passed the 0.6 Ftu level.

With the introduction of new media into a pilot column, the media was backwashed and air scoured several times. The fines common with new media and the newly created fines due to fracturing of some of the new media during backwash were removed prior to carrying out filter tests. This usually meant the removal of the top one inch of media. Most of the results listed in this paper were obtained with 13 inches of 0.45 mm effective size sand (e.s.) and 22 inches of coal unless otherwise indicated.

Backwashing

With the absence of a suitable surface wash device, the airscour was a valuable addition to the pilot filter operation. It was found to be necessary for the prevention of mud ball formation and slime growth. The backwash technique consisted of lowering the water level to two feet above the media. The air

was introduced at 7 psig into the clear well and allowed to continue for one minute. The filter was then given a normal backwash at a maximum rate of 20 Igpm/sq ft. For the 1.55 mm e.s. coal, the 20 Igpm/sq ft flow rate was necessary to ensure proper separation of the sand and the coal after the backwash. Bachwash rates of less than 15 Igpm/sq ft would result in a larger than normal coal-sand interface region and poor bed expansion.

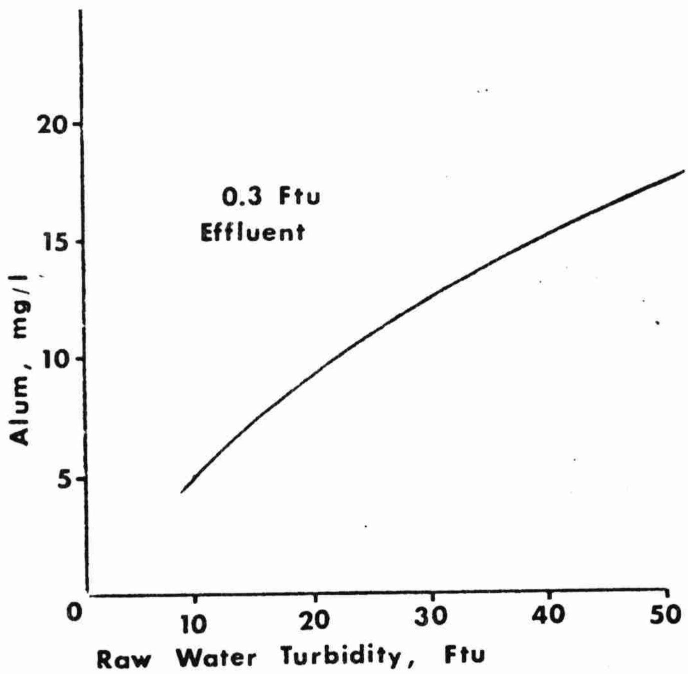
2.2. Effluent Quality Objective

The effluent turbidity objective of the pilot scale work was 0.3 Ftu or less. It was felt that 0.3 Ftu from the filters represented an effluent quality that would meet the Ministry of the Environment objective of 1 Ftu delivered to the consumer. In addition, an increase in the coagulant dosage to obtain an effluent below 0.3 Ftu would significantly reduce the length of filter runs.

The relationship between alum dosage and effluent quality from various raw water turbidities is illustrated in Figure 2.

FIGURE 2

ALUM DOSAGE vs RAW WATER TURBIDITY



This relationship was found to be consistent for all media sizes at all test sites except those at Harrow on Lake Erie. The effluent quality using Lake Erie water was found to be superior to that obtained at test sites on Lake Huron. It is felt that either or both the raw water pH or the nature of the suspended material may have contributed to this difference between the treated water from the two lakes.

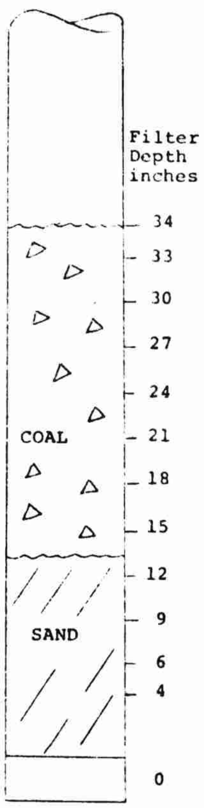
2.3 Floc Distribution

For most of the filter runs discussed in this paper a headloss distribution chart similar to Table 1 has been calculated. These are summarized in the Appendix Supplement. The floc distribution was determined for the filter at terminal headloss. The percentage **headloss** occurring in any given area of the filter can be quickly determined from such a chart.

For example, in Table 1 the percent of the total headloss occurring in the top 4 inches of the coal is 64.7 (43.7 + 21.0) for the 0.9 mm e.s. coal, 34.4 for the 1.05 mm e.s. coal and only 20.6 for the 1.55 mm e.s. coal.

TABLE 1

HEAD LOSS DISTRIBUTION RESULTS



Run #	56	56	56
Coal Size mm	0.9	1.05	1.55
Head Loss %			
	43.7	20.1	6.8
	21.0	14.3	13.8
	11.2	8.0	8.5
	6.6	6.6	6.1
	3.2	4.9	6.5
	2.5	3.3	9.2
	1.3	2.1	9.2
	5.0	14.0	15.3
	3.4	20.2	14.2
	0.7	4.2	7.2
	0.5	1.2	2.3
	0.9	1.2	0.9

Filtration Rate - 4 Igpm/sq ft
Raw Water Turbidity - 13 Ftu
Alum - 12 mg/l
Flocculation Gradient - 20 sec^{-1}

There is an increased penetration of the floc into the coal-sand interface region for the coarser coal. In the example given, the percent head loss for the interface region was 8.4 (5.0 + 3.4) for the 0.9 mm e.s. coal and 34.2 for the 1.05 mm e.s. coal. With the greater intermixing when using the 1.55 mm e.s. coal, the percent headloss is 38.8 (14.2 + 15.3 + 9.2) for this region. This increased dependence of the coarse media on retaining the floc at the interface is an important factor leading to breakthrough problems with the coarse coals.

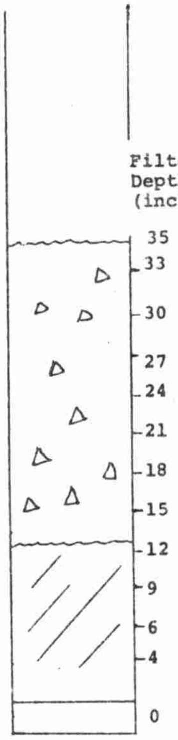
The headloss distributions included in the Appendix Supplement are those measured at the conclusion of the filter run. During the course of a filter run, the headloss will distribute itself in a manner similar to that measured at the conclusion of a run. Table 2 illustrates this point. The headloss distributions were calculated after filtering for 4, 13, 29.5 and 34.5 hrs. A comparison of the final headloss distribution (86" total) with those earlier in the filter run shows that the rate of increase is relatively constant throughout the filter bed during the filtration cycle.

TABLE 2

HEADLOSS DISTRIBUTION RESULTS

Run # 4

Coal Size 1.05 mm



Filter Time hr	4	13	29.5	34.5
Total Headloss (in.)	25	41	72	86
Headloss %				
	28.6	35.0	29.3	26.3
	10.7	10.6	10.6	10.1
	4.8	6.3	6.1	8.9
	2.4	3.0	3.4	3.9
	1.0	0.4	2.7	2.9
	0.9	0.8	2.3	2.4
	0.5	0.8	1.6	1.3
	19.2	16.9	18.6	20.1
	19.2	15.2	15.5	15.4
	7.1	6.3	5.8	5.6
	1.2	1.7	1.8	2.1
	4.8	3.0	2.3	2.4

Filtration Rate 4 Igpm/sq ft
Alum 6 ppm

In cases of filter breakthrough, a sharp increase occurs in the headloss within the central and lower sand layers prior to breakthrough.

Optimum Headloss Distribution

From the observations of numerous tests, it is preferred that 75 percent of the total head loss takes place in the coal region to minimize possible filter breakthrough and produce long filter runs. This will mean the use of a filter aid more often for the coarser coals than for the finer coals.

3 PROBLEM AREAS

GENERAL

The existing Ontario direct filtration plants have been troubled by operational problems that have arisen in three main areas:

1. High raw water turbidity levels of 100 Ftu or greater have led to shortened filter runs due to the clogging of the filter bed or filter breakthrough prior to 8 ft of headloss.

2. Diatom levels in excess of 1000 Asu/ml have substantially shortened the length of filter runs due to the "blinding" of the filter surface.

3. Residual aluminum levels above 0.1 mg/l are suspected to have produced slime coatings on pipeline surfaces. In severe cases, "after-floc" has been produced.

The results of the pilot plant work indicate that, for turbidity levels up to 175 Ftu, filter breakthrough can be eliminated with the use of polymers. The correct dosage of polymer can easily be determined when the polymer is used in conjunction with interface turbidity monitoring devices.

It is possible to filter diatom levels up to 5000 Asu/ml and still have filter runs near 12 hrs with acceptable treated water quality if the filtration rate does not exceed 3.0 Igpm/sq ft and the effective size of the filter coal is in the range of 1.5 to 1.8 mm.

The residual aluminum levels can be kept below 0.1 mg/l by correct pH control if the alkalinity of the treated water remains above 20 mg/l.

3.1 High Raw Water Turbidity

High raw water turbidity problems can limit the direct filtration process in two ways. It can result in a high coagulant demand that will result in shortened filter runs and strain backwash water facilities. It can also lead to early breakthrough problems which, if left unchecked, can result in high turbidity water including coagulant entering the distribution system.

Plant High Turbidity Results

After a severe storm on Lake Huron in March, 1973, the raw water turbidity reached levels close to 200 Ftu. Table 3 summarizes the operating conditions for this period of time. No polyelectrolyte feed facilities were available to the plant. The filters were backwashed on effluent quality as breakthrough occurred often.

TABLE 3

HIGH RAW WATER TURBIDITY AT LAKE HURON PLANT

Date (March 1973)	Alum	Turbidity Raw	Turbidity Eff.	Filter Rate	Average Run Time*
	mg/l	Ftu	Ftu	Igpm/sq ft	hr
19	28.5	160	1.1	1.7	16
20	29.8	120	0.8	1.7	13
21	26.5	85	1.4	1.7	18
22	28.3	70	1.4	1.8	18
23	21.5	50	1.2	2.1	14
24	23.0	45	1.2	2.3	13
25	22.6	40	1.0	1.9	9
26	19.6	42	1.1	1.8	22
27	16.4	45	1.1	1.5	25
28	24.6	24	0.9	2.1	27
29	18.0	18	0.7	1.2	35

*Filter runs terminated at breakthrough

*Filter times for 0.95 mm coal. The 1.5 mm coal filters had filter runs about two thirds as long as those listed.

Observations of Table 3 are that the effluent turbidity of the plant was kept near Ministry standards (less than 1 Ftu) for most of the storm period despite breakthrough problems. Several of the filters experienced filter surface wash breakdown and these filters were put out of service. This resulted in a higher filtration rate for the other filters and subsequently shorter filter runs resulted.

Similar results are found in the operation of the Port Elgin plant on Lake Huron. The Red Rock water treatment plant on Lake Superior is troubled during the spring runoff where high turbidity from a nearby river leads to filter breakthrough problems. Mixing and high velocity problems in the flocculation area have reduced the effectiveness of the filter aids at this plant.

3.1.1. Artificial vs Natural Turbidity

Several high turbidity tests were carried out at Sarnia. Some work was carried out in 1972 during the fall storms. With the frequency of these storms being unpredictable, tests in 1973 used clay as an artificial turbidity. Preliminary work with the clay established that the filter performance characteristics for both the artificial turbidity and natural turbidity were close enough to justify further work with artificial turbidity. Table 4 outlines some typical turbidity results. Complete results of these tests are listed in Appendix (1).

TABLE 4

PILOT FILTER PERFORMANCE

Natural Turbidity vs Artificial Turbidity

Run #	Filter Media Eff. Size mm	Alum mm	Turbidity Raw Ftu	Turbidity Eff. Ftu	Final Head Loss ft	Filter Time hr
S-22	0.9	15	20*	0.18	6.0	11.5
	1.05	15	20*	0.18	4.5	11.5
	1.55	15	20*	0.20	3.0	7.2
61	0.9	12	14	0.20	5.8	15.0
	1.05	12	14	0.23	4.3	13.5
	1.55	12	14	0.23	4.3	11.8
18	0.9	15	20	0.15	7.5	9.5
	1.05	15	20	0.20	4.0	8.5
	1.55	15	20	0.20	2.5	4.5

Filtration Rate	- 4 Igpm/sq ft
Flocculation Velocity Gradient	- 20 sec^{-1}
Flocculation Time	- 18 min

* Natural Turbidity

Artificial Turbidity

Table 5 (Appendices (2) and (3)) summarizes work carried out in the summer of 1973 at Sarnia with artificial turbidity added to the raw water to achieve higher raw water turbidities. The results listed here reveal the advantage of adding the correct amount of alum (Run #20). Underdosing alum (Run #22) and overdosing alum (Run #21) results in breakthrough

occurring earlier into the filter run. It would be very difficult to operate a plant under the conditions listed as the filter times would be very short.

TABLE 5

ARTIFICIAL TURBIDITY - NO POLYELECTROLYTE

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Alum	Breakthrough Head Loss	Run Time
	mm	Ftu		mg/l	ft H_2O	hr
22	0.9	40	0.35	12	2.6	5.0
	1.05	40	0.35	12	2.3	6.0
	1.55	40	1.50	12	1.8	3.0
20	0.9	40	0.25	17	5.8	9.5
	1.05	40	0.25	17	3.7	7.5
	1.55	40	0.25	17	2.8	5.5
21	0.9	40	0.18	28	1.8	2.5
	1.05	40	0.20	28	2.0	2.8
	1.55	40	0.18	28	1.8	2.5
25	0.9	80	0.25	20	2.5	4.5
	1.05	80	0.25	20	2.0	3.3
	1.55	80	0.25	20	1.8	2.8

Filtration Rate - 4 Igpm/sq ft

Flocculation Velocity Gradient - 20 sec^{-1}

Flocculation Time - 18 min

Appendix 4 lists other results obtained at a filtration rate of 6 Igpm/sq ft during periods of high natural turbidity in 1972 at Sarnia. In most cases, the results are characterized by breakthrough prior to terminal headloss. The early breakthrough emphasizes the difficulty in operating a treatment plant without some means of strengthening the floc during periods of high raw water turbidity.

3.1.2 Polymer Filter Aid

Table 6 (Appendix 5) shows how polymer, added as a filter aid, can prevent filter breakthrough.

TABLE 6

ARTIFICIAL TURBIDITY - POLYELECTROLYTE ADDED

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Alum	Polymer*	Final Head Loss	Run Time
	mm	Ftu		mg/l	mg/l	ft H_2O	hr
24	0.9	40	0.17	17	0.10	8+	13.0
	1.05	40	0.25	17	0.10	6.5	12.0
	1.55	40	0.18	17	0.60	8+	9.2
27	0.9	80	0.20	20	0.20	8+	11.0
	1.05	80	0.25	20	0.25	8+	11.0
	1.55	80	0.25	20	0.45	8+	9.0
33	0.9	175	0.28	20	0.40	8+	7.5
	1.05	175	0.35	20	0.40	8+	9.8
	1.55	175	0.31	20	0.40	8+	12.5

Filtration Rate - 4.0 Igpm/sq ft

Flocculation Velocity Gradient - 20 sec^{-1}

Flocculation Time - 18 min

*Separan NP10

In run number 24, 0.1 mg/l of Separan NP10 was added near the last section of the flocculator. An additional 0.5 mg/l was added just above the 1.55 mm filter media. No attempt to optimize the polymer feed (for each filter coal) was made. As a result, the filter containing the 1.05 mm coal was slightly underdosed and filter breakthrough took place.

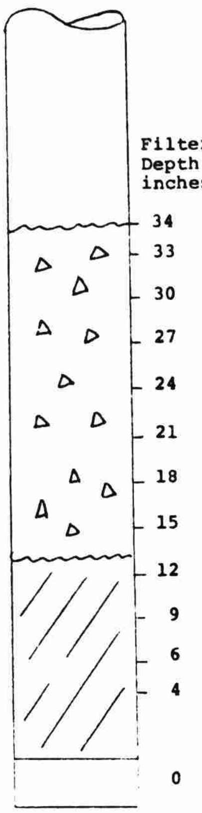
Floc Distribution

One can determine whether the filters have received the proper dose of polymer with the aid of the headloss distributions as listed in Table 7.

TABLE 7

HEAD LOSS DISTRIBUTION RESULTS

Polyelectrolyte Addition



Run #	27	27	27
Coal Size mm	0.9	1.05	1.55
Polymer* mg/l	0.2	0.25	0.45
Head Loss %			
	36.6	29.9	44.3
	37.8	29.4	36.0
	13.6	15.1	10.7
	4.9	6.6	3.4
	2.5	0.4	1.0
	0.0	-	-
	-	5.2	0.6
	0.9	3.9	2.3
	1.9	7.6	0.6
	0.9	1.3	0.7
	0.1	0.3	0.0
	0.8	0.3	0.4

Filtration Rate - 4.0 Igpm/sq ft
Alum - 20 mg/l
Raw Water Turbidity - 80 Ftu

*Separan NP10

An excess percentage of headloss in the filter coal and short filter runs are characteristics of polymer overdosing. For run number 27, the filter containing 0.9 mm e.s. coal had

95 percent of the headloss occurring in the coal. Optimum headloss percentages are in the range of 75-80 percent in the coal and 20-25 percent in the sand. It is probable that polymer dosages for the 0.9 mm coal, under the conditions listed, could have been reduced to 0.06 - 0.07 mg/l to allow deeper floc penetration. The filter time may then have been several hours longer. Similar conclusions can be drawn for the 1.55 mm e.s. coal. The filter containing the 1.05 mm e.s. coal had 87 percent of the headloss occurring in the coal and the run times could be considered close to the optimum.

High Filter Rates

The results of filter runs carried out in 1972 are listed in Table 8 (Appendix 6).

TABLE 8

High Turbidity plus Polymer at 6 Igpm/sq ft

Run	Coal e.s.	Polymer*	Raw Turb.	Final Headloss	Run Time
	mm	mg/l	Ftu	Ft	hr.
S-29	0.9	0.1	35	8	8.1
	1.05	0.1	35	6.5	8.2
	1.55	0.1	32	4.5	5.6
S-30	0.9	0.2	44	8	5.5
	1.05	0.2	44	8	7.3
	1.55	0.2	44	5.5	5.0

Filtration Rate 6 Igpm/sq ft
Alum 10 ppm

* Separan NP10

The findings reveal that breakthrough can be eliminated without difficulty for coal sizes of 1.0 mm e.s. or less even at filtration rates of 6 Igpm/sq ft at turbidity levels near 40 Ftu or less. The filter runs are short however ($<$ 10 hrs) and plant operation would be limited. The prevention of filter breakthrough with the 1.55 mm e.s. coal will require a greater amount of polymer than that for the smaller coal sizes.

Polymer Comparison

Table 9 (Appendix 7) outlines the findings of tests carried out to evaluate three polymers namely, Separan NP10, Purifloc N20, and Nalcolyte 8171.

TABLE 9

Comparative Study of Polymers

Run #	Coal mm	Polymer mg/l	Final Headloss ft	Run Time hrs	Headloss Coal %	Headloss Sand %
67	0.9	0.11*	7.0	9.3	76	24
	1.05	0.11	5.5	8.8	55	45
	1.55	0.11	5.4	7.5	44	56
68	0.9	0.105**	8	3.0	96	4
	1.05	0.105	8	4.4	94	6
	1.55	0.105	8	5.7	95	5
69	0.9	0.10***	8	10.2	68	32
	1.05	0.10	5.6	10.0	53	47
	1.55	0.10	6.1	10.0	43	57

Filtration Rate	4 Igpm/sq ft
Alum	18-19 ppm
Raw Turbidity	30 - 32 FTU

* Separan NP10
** Purifloc N20
*** Nalcolyte 8171

The results indicate that Purifloc N20 is a superior floc strengthener in this application to either of the other two polymers. This is characterized by the extremely high percentage of floc trapped in the coal layer of all three filters. It is expected that the Purifloc N20 dosage could be reduced to less than half of that tested and obtain results similar to those of the other two.

3.1.3 Interface Turbidity

It has been determined that the use of a filter aid can allow the filters to be operated at higher rates (up to 6 Igpm/sq ft) without the danger of turbidity breakthrough. If the optimum amount of polymer is added the length of filter runs could be extended to obtain the maximum filter time under severe conditions. If the polymer is underdosed, breakthrough will occur prior to terminal headloss. Overdoses of filter aid can lead to problems with excessive headloss buildup. Difficulties have also been reported with backwashing the filters after polymer overdose[6].

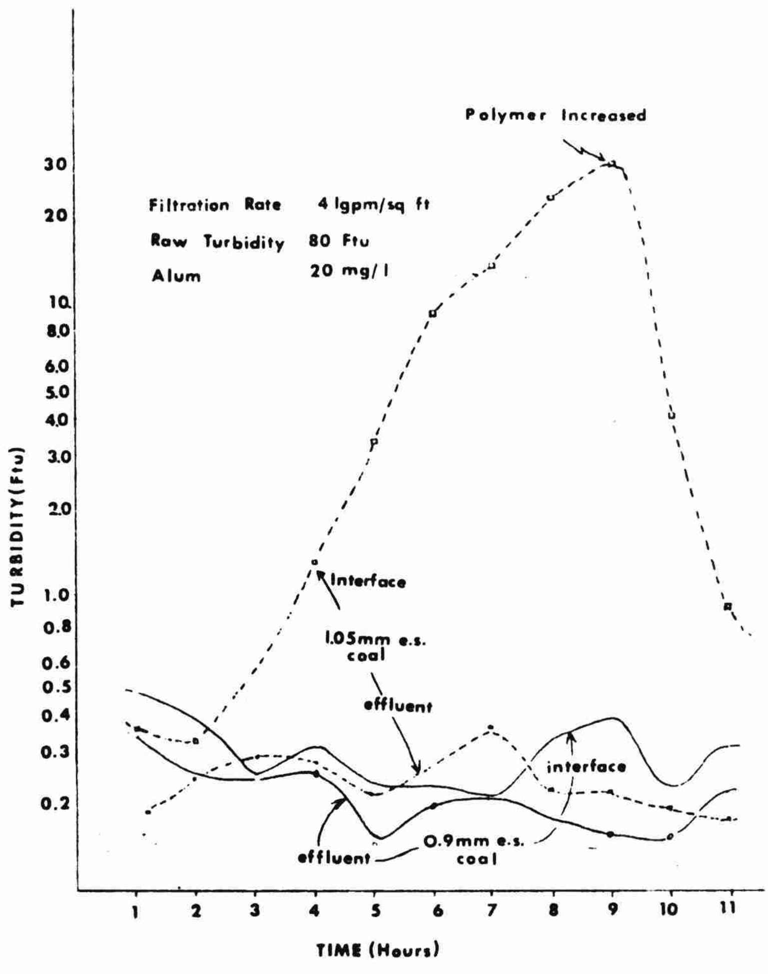
Most of the methods practiced for determining the proper amount of filter aid have been to monitor the filter effluent and adjust the polymer dosage accordingly. This technique can be time consuming and inefficient. Harris [7] used an interface monitoring system which allows the operation to continuously determine the optimum amount of filter aid to produce the maximum amount of high quality water. The technique consists of drawing off continuously a sample for turbidity analysis of water from just above the coal-sand interface region and from the

filter effluent. A change in turbidity at the interface signals the necessity of making a corresponding change in the polymer dosage. This way both underdosing and overdosing of the polymer can be kept to a minimum.

During polymer feeding conditions, it is believed that interface turbidity levels as high as 5-10 Ftu can be tolerated for the duration of the filter run. Levels of turbidity above 10 Ftu at the interface will probably lead to filter breakthrough prior to 8 ft of headloss. Figure 3 outlines the turbidities measured during filter Run #27 where the interface turbidity level for the 0.9 mm filter coal remained low (< 0.4 Ftu) throughout the filter run. This indicates that the filter was overdosed with polymer. This finding complements the same conclusion discussed earlier under headloss distribution.

FIGURE 3

INTERFACE TURBIDITY



The interface turbidity of the filter containing the 1.05 mm coal steadily increased until filter breakthrough was expected (after 9 hrs). Because of this, the polymer dosage was increased to 0.45 mg/l from 0.1 mg/l. The interface turbidity quickly fell to a lower level (29 Ftu to 4 Ftu) and a subsequent cutback of the polymer was made after 10 hours.

Although not shown in Figure 3, the polymer addition to the 1.55 mm coal was reduced from 0.6 mg/l to 0.45 mg/l after 7 hours due to the low interface turbidity and a rapid headloss increase. After this cutback of polymer, the rate of increase of the headloss was reduced but there was no substantial increase in the interface turbidity levels. An earlier cutback in polymer would have increased the filter run time considerably.

3.1.4 <u>Dosing Point</u>

The most efficient dosage point on the pilot plant of the filter aid polymer was found to be 3 to 4 ft above the surface of the filter bed. This would correspond to the inlet section to a plant scale filter. It was found that if the polymer was added in the flocculation section, a higher dosage was required to prevent filter breakthrough.

The Lake Huron Water Supply System is installing a polyelectrolyte feed system with interface turbidity monitoring. It is believed that turbidity levels near 200 Ftu can be tolerated for short periods of time ($<$ 24 hrs) with this arrangement.

The maximum filtration rate could not exceed 3 Igpm/sq ft and filter runs of 12 hours would be considered average.

March Storm 1974

The results during a storm in March 1974 are listed in Table 10.

TABLE 10

Lake Huron Water Supply System
High Raw Water Turbidity - Polymer Protection

Filter Coal	Alum	Turbidity Raw	Turbidity Eff.	Filtration Rate	Filter Time	Final Headloss
e.s.	mg/l	Ftu	Ftu	Igpm/sq ft	hrs	ft
0.95	20	40	0.45	1.6	24.5	6.5*
0.95	20	50	0.45	1.6	26.	6.3*
0.95	20	18	0.3	1.4	29.	7.0*
0.95	15	25	0.25	1.1	40+	7.5*
0.95**	20	40	0.2	1.5	22	8
0.95**	20	50	0.2	1.5	26	8
0.95**	20	18	0.2	1.2	32	8
0.95**	10	25	0.4	1.0	48	8
1.55**	20	40	0.3	2.2	24	8
1.55**	20	50	0.2	2.2	18	8
1.55**	20	18	0.4	1.9	18	8
1.55**	10	25	0.4	1.6	33	8

* Filter Breakthrough
** Polymer Dose 0.1 mg/l

Half of the plant was equipped to feed polymer on a temporary basis. As can be seen in the table, those filters that did not have the advantage of a filter aid suffered breakthrough prior to terminal headloss. The filters where polymer was dosed had shorter filter runs but in no case was

filter breakthrough recorded. A significant increase in the length of filter runs was recorded on the fourth day of the high raw water turbidity after the alum was reduced to 10 mg/l.

The polymer was fed into the flocculated water conduit leading to the filters. It was observed that the effect of the polymer on filter performance was reduced for those filters farthest away from the dosage point.

With the proper interface turbidity monitoring device to optimize the polymer feed, the length of filter runs during this time might have been increased 25 to 50 percent.

3.2 Algae

The Lake Huron Water Supply System is the only direct filtration plant of the four mentioned that is severely troubled with algae. The plant was first troubled with short filter runs due to the filters being clogged with diatoms in 1969. The diatoms, a microscopic form of plant life, were predominantly Fragilaria, Tabellaria, Synedra, and Melosira. Their arrival coincides with raw water temperatures usually in the range of 50 - 58^{o}F. During the late spring, their numbers can rise to 5000 Asu/ml. With the influx of warmer weather and a rise in water temperature, their numbers diminish to less than 200 Asu/ml in late July.

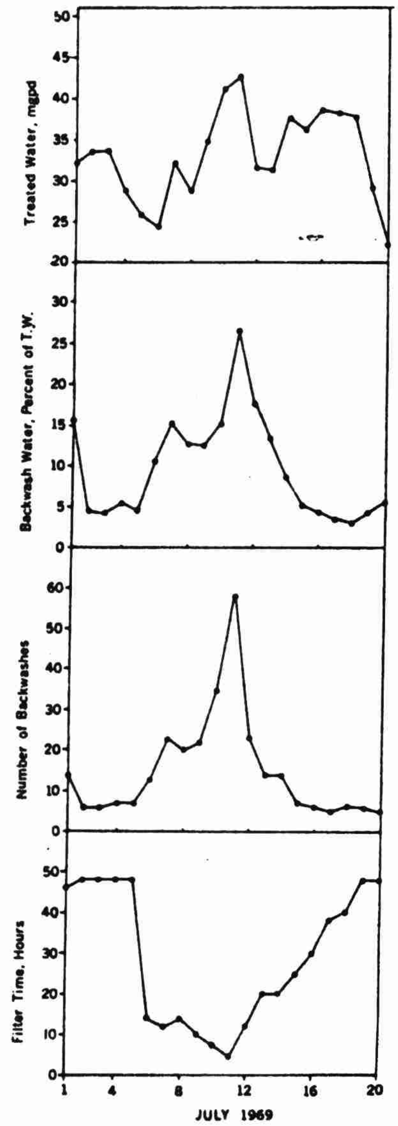
Diatoms have a history of causing short filter runs in water treatment plants on the Great Lakes. One of the worst problems occurred in the fall of 1959 [8].

3.2.1 Plant Capacity Reduction - 1969, 1970

Figure 4 illustrates the short filter run problems that these diatoms caused at the Lake Huron Water Supply System at Grand Bend during July, 1969.

FIGURE 4

LAKE HURON FILTER PLANT OPERATION



The worst day on the graph shows that filter runs at 2.3 Igpm/sq ft were reduced to 4.5 hours and the backwash water on this day rose to 26.7 percent of the total treated water. The breaking up and removal of the algae matte was accomplished with little difficulty with an adequate backwash water supply. With the plant designed for a backwash water supply of five percent of the treated water, backwash water requirements at 15$^+$ per cent of the treated water severely handicapped the plant output.

In 1970, diatoms again reduced filter runs in May and June. The high water demand at this time of the year added to the problems. Several experiments were carried out on the filters by Research Branch and plant staff. These included running the Palmer Sweeps while filtering to prevent an algae matte from forming. Short backwashes of three to four minutes at an increased rate of 20 Igpm/sq ft (the previous rate was 15 Igpm/sq ft) were also tried. Although the net water production increased slightly, the short filter run times remained as a serious problem.

3.2.2 Pilot Plant - Coarse Coal

In the spring of 1971, three six inch diameter columns each six feet high were set up in the plant at Grand Bend. Several runs were carried out with plant filter media (coal size 0.9 mm e.s. and 1.7 uniformity coefficient (u.c.) and sand 0.5 mm e.s. and 1.8 u.c.) to confirm filter performance of the pilot columns with that of the plant. Our findings allowed correlation of pilot filter column work with that of plant filters. With this phase completed in late May, tests with

coals of different effective sizes were carried out in early June. The sizes of coals tested and length of filter runs obtained with these sizes are listed in Table 11.

TABLE 11

Lake Huron Pilot Filter Studies
June 1971

Depth	Filter Coal e.s.	u.c.	Average Run Time to 4 ft Headloss hrs	Headloss Coal %	Headloss Sand %
18	1.2	1.4	5.2	94	6
18	1.4	1.25	7.4	90	10
18	1.7	1.45	11.9	66	34
18	2.0	1.45	17.5	36	64

Filtration Rate	4.0 Igpm/sq ft
Raw Water Turbidity	5 Ftu
Alum Dosage	10 mg/l
Effluent Turbidity	0.5 Ftu

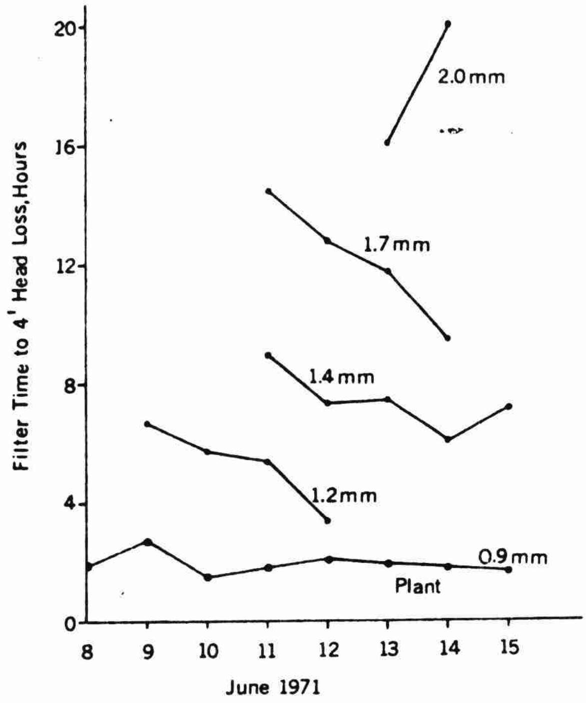
Due to the pilot filter construction limitations, all filter runs were terminated at four feet of headloss. All coal media were supported with twelve inches of sand with an e.s. of 0.45 mm and a u.c. of 1.5. The coarse media (1.4, 1.7, and 2.0 mm e.s.) were screened and sized from a limited supply of coarse coal. The water for the pilot filter studies was obtained from a conduit as the water left the plant flocculation chamber to enter the plant filter boxes.

Diatom Penetration into
Filter Coal

A review of the data outlined in Table 11 and Figure 5 indicates that with the increased penetration of the diatoms into the filter coal, longer run times result.

FIGURE 5

EFFECT of COAL SIZE on FILTER TIME



Filtration Rate	**4.0 Igpm/sq ft**
Alum Dosage	< 8 **mg/l**
Raw Water Turbidity	<5 Ftu
Effluent Turbidity	< 0.5Ftu

With the 2.0 mm e.s. coal this deep penetration resulted in a large headloss buildup at the coal-sand interface. Examinations of the filter effluents from all coal sizes tested revealed that no diatoms passed through the filters despite the

deep penetration of the filter beds, although other research (9,10) has indicated that some algae species may pass through the sand layer of the filter bed.

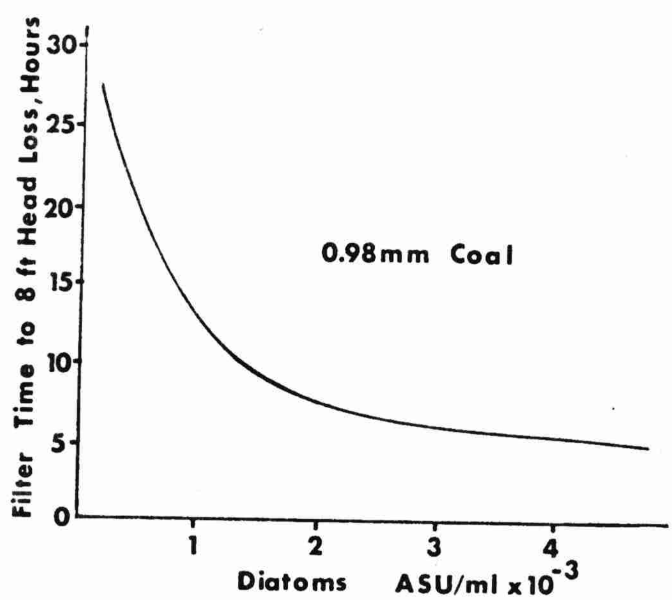
Coarse Filter Coal

Coal with an e.s. of 1.4 - 1.7 mm appeared to be the best size to handle the diatom levels (2,000 - 5,000 Asu/ml) encountered during this test period. Examination of plant filter data indicated that filter run time to four feet of headloss was approximately half of the run time needed to reach eight feet of headloss. This indicates that for the 1.7 mm coal, the filter times would be 19 to 28 hours to eight feet of headloss. These compare favourably with the 2.5 - 3.5 hour filter run with the plant coal (0.9 mm e.s.).

Figure 6 indicates the relationship between the level of diatoms and the length of filter runs for a plant filter containing coal with an effective size of 0.98 mm.

FIGURE 6

DIATOM CONCENTRATION
vs
FILTER TIME



Filtration Rate 3.0 Igpm/sq ft
Alum < 8 mg/l

At the filtration rate of 3.0 Igpm/sq ft and the low alum dosage of less than 8 mg/l, the length of filter runs decreased from approximately 25 hours plus with less than 250 Asu/ml diatoms to 12.5 hrs when the diatom loadings reached 1000 Asu/ml. Filter runs as short as 1 3/4 hrs have been recorded for diatom levels of 8,000 - 9,000 Asu/ml. For the plant at Grand Bend to operate satisfactorily, the filter runs must be at least twelve hours in length at a filtration rate of 3.0 Igpm/sq ft. The pilot filter work indicated that coal in excess of 1.4 mm e.s. was necessary to achieve this filter time during the high diatom period.

3.2.3 Plant Trial with Coarse Coal

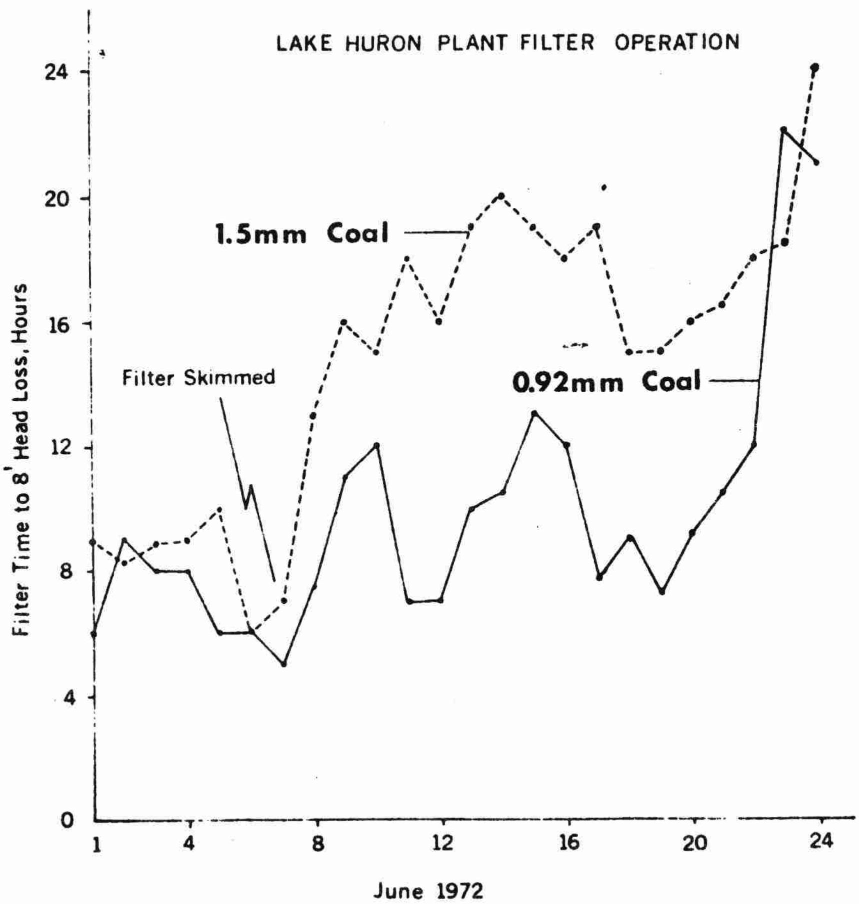
One filter at the Grand Bend plant was converted to coarse coal during the winter of 1972. The delivered coarse coal size was 1.5 mm e.s. and had a u.c. of 1.5. The filter was placed into service in March, 1972. On June 8, the filter was examined, and as an accumulation of fines was found to exist, 1 - 2 inches were skimmed off.

For the month of June, 1972, both the plant test filter and a regular plant filter were run at 3.0 Igpm/sq ft. Algae counts (90 percent diatoms) revealed levels over 3,000 Asu/ml on several occasions. The results are outlined in Figure 7. After the test filter was skimmed, the minimum length of filter runs was twelve hours. Effluent quality of the test filter matched that of the regular plant filter. The diatom levels dropped to below 400 Asu/ml on June 23, and did not return in significant numbers again that year.

Both the test filter and the regular plant filter were run at 3.0 Igpm/sq ft until the end of October. The length of runs from the two filters in the absence of diatoms was similar with the test filter having slightly longer runs. Breakthrough problems were few because the fall raw water turbidity rarely exceeded 15 FTU.

FIGURE 7

LAKE HURON PLANT FILTER OPERATION



Filtration Rate 3.0 Igpm/sq ft

Alum Dosage <10 mg/l

Raw Water Turbidity <5 Ftu

Effluent Turbidity <0.4 Ftu

Plant Coarse Coal - Three
Additional Filters 1973

Conversion of three additional plant filters to 1.5^+ mm e.s. filter coal was made in 1972. The filter coal had an effective size of 1.7 mm and a uniformity coefficient of 1.6. The coal was purchased from a different supplier than the 1972 coarse coal supplier. It was found to have a higher specific gravity. As a result, there was a greater intermix of the sand and coal layers after backwashing. The sand layer was measured to be within 3 inches of the top of the media. The intermix was felt to be detrimental in allowing the diatoms to penetrate into the filter coal. Nevertheless, the filters were placed into service prior to the 1973 algae run. There was no skimming of the filters prior to the algae arrival due to the lack of visible fines on the surface of the media.

The results of the coarse coal filter runs for 1972 and 1973 are listed in Table 12. The coarse coal filters had filter times approximately double those of the 0.92 mm e.s. filter coal. The minimum filter times of 8 and 9 hours represent a borderline filter performance. That is, the plant could operate successfully with filter runs as low as 8 hours but this requires the operator to be continually alert to the problem to keep the backwash water to a minimum. The algae levels of $6{,}000^+$ Asu/ml causing these short filter runs lasted less than 12 hours. The history of the plant operation has indicated that extremely high algae levels, (> 6,000 Asu/ml), last for a maximum time of 24 hours. They usually arrive and last for 5 to 8 hours at a time.

TABLE 12

ALGAE RUN SUMMARY

Lake Huron Water Supply System

1972 (June 7 to June 22)

Filter Coal e.s.	Filter Rate Igpm/sq ft	Time Between Backwashes Avg. hrs	Time Between Backwashes Min. hrs	Production Average Ig/sq ft
0.92	3.0	9.5	5	1710
1.55	3.0	16.8	13	3020
1973 (June 13 to July 18)				
0.92	3.0	8.7	4	1570
1.55	3.0	15.6	9	2810
1.7	3.0	15.4	8	2770

1972	Diatoms	Avg. 1800 Asu/ml Max. 5500 Asu/ml
1973	Diatoms	Avg. 1300 Asu/ml Max. 4500 Asu/ml

Early in 1974, one of the 3 new filters of coarse coal was examined and an excess of fines was removed prior to the algae arrival. The two other filters were not skimmed. The filter installed in 1972 had a small amount of fines but skimming was not felt to be necessary.

Diatoms - 1974

The 1974 filter operation is listed in Table 13.

TABLE 13

ALGAE SUMMARY 1974

Lake Huron Water Supply System

May 21 - June 16

Filter Coal e.s.	Filter Rate	Time Between Backwash Average	Minimum	Production * Average	Algae Ave.	Max.
mm	Igpm/sq ft	hrs	hrs	Ig/sq ft	Asu/ml	
0.92	3.0	7.2	1.8	1300	9000	2,500
1.55*	3.0	23.0	9.0	4150	9000	2,500
1.7 *	3.0	22.6	8.0	4070	9000	2,500

* Adjust Filtration Rate

The results for the 1.55 mm and the 1.7 mm e.s. coal were adjusted to the filtration rate of 3.0 Igpm/sq ft for comparison purposes even though their actual operating filtration rate was lower. This adjustment is considered reasonable because the production per filter run during the algae run has been found to be independent of the filtration rate (e.g. a filter operating at 2 Igpm/sq ft would run twice as long as the same filter filtering at 4 Igpm/sq ft).

Algae levels greater than 1,500 Asu/ml lasted for almost a month. On the worst day, the algae counts exceeded 9,000 Asu/ml but this high level was maintained for only 6 or 7 hours. The 1.55 mm and the 1.7 mm e.s. coal produced over three times as much water per filter run as the 0.92 mm e.s. coal. Parallel pilot plant filter studies were carried out with sand plus 18 inches of #2 anthrafilt (one inch skimmed off). The results indicate that filter runs exceeding 20 hours under all the conditions encountered in 1974 could be expected.

Sedimentation tests on a pilot plant scale were also performed during the algae run. For a retention time of 3 hours and an alum dosage of 20 mg/l, close to 80% of the diatoms could be settled out.

Future plans for the water plant include the changing of two more filters to coarse coal. A more intensive study of the relationship between the coal size, the specific gravity and the coal sand intermix is also planned. A complete report on filter coal size versus algae size, concentration, genus and removal by sedimentation is also scheduled to be written.

3.3 Residual Aluminum

The residual aluminum content of the treated water in our tests was found to be pH dependent. It varied with the pH in a manner outlined in Figure 8.

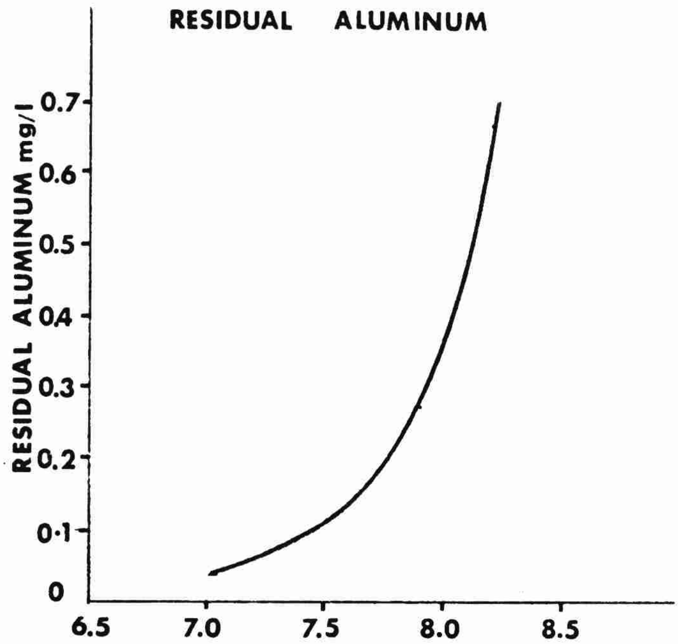
FIGURE 8

LAKE HURON

TREATED WATER pH

vs

RESIDUAL ALUMINUM



This finding is similar to that found by Packham [11]. A treated water pH greater than 7.45 units results in an effluent residual content greater than 0.1 ppm. It has been theorized that residual aluminum could lead to coatings on pipeline surfaces which could result in a reduction in flow capacity [12]. In addition, extremely high residual aluminum levels (probably exceeding 0.4 mg/l) could conceivably result in "after-floc" formation.

The dependence of the residual aluminum on pH prompted a short study of the treated water pH versus the filter performance.

Alum Dosage vs
Effluent pH

Previous data, Figure 9, had indicated the relationship between the alum dosage and the treated water pH for Lake Huron water at the time of the pilot filter studies.

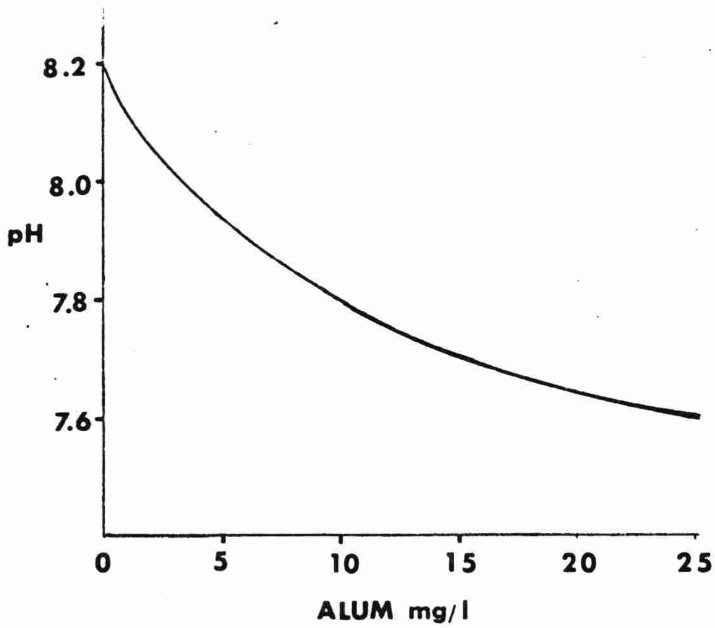
FIGURE 9

LAKE HURON

TREATED WATER pH

vs

ALUM DOSAGE

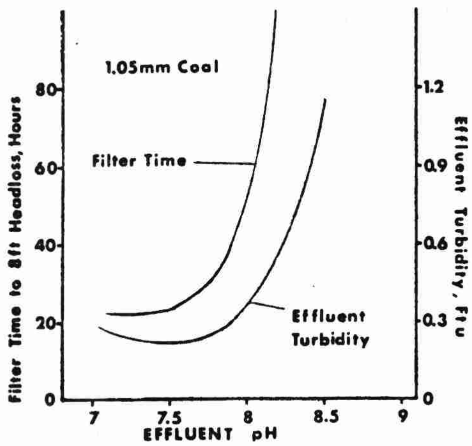


3.3.1 pH vs Filter Performance

Tests carried out at treated water pH levels of 7.0, 7.85, 8.2 and 8.85 are summarized in Table 14. The results for the 1.05 mm coal are plotted in Figure 10. Treated water pH levels near 7.0 were obtained with the aid of sulphuric acid while sodium carbonate was added to reach a level of 8.85.

FIGURE 10

THE INFLUENCE OF pH ON FILTER TIME and EFFLUENT TURBIDITY



Filtration Rate 6.0 Igpm/sq ft
Alum 6mg/l

TABLE 14

THE EFFECT OF pH ON FILTER PERFORMANCE

Run Number	Raw Water pH	Run Time	Turbidity Raw	Turbidity Eff.	Filter Coal Eff. Size
	pH	hr	Ftu	Ftu	mm
30	7.0	23.0	1.5	0.30	1.05
29	7.85	26.5	1.5	0.25	1.05
31	8.2	110*	1.5	0.41	1.05
31	8.85	280*	2.3	1.1	1.05
30	7.0	22.0	1.5	0.30	1.55
29	7.85	31.0	1.5	0.25	1.55
31	8.2	130*	1.5	0.42	1.55
31	8.85	310*	2.3	1.1	1.55
30	7.0	16.5	1.5	0.30	0.9
29	7.85	22.0	1.5	0.23	0.9
31	8.2	75*	1.5	0.45	0.9
31	8.85	140*	2.3	1.1	0.9

Filter Rate - 6 Igpm/sq ft
Alum Dose - 6 mg/l
Floc Gradient - 20 sec^{-1}
Floc Time - 14.5 min

*Projected from Head Loss Rate of Increase

Appendix 8 outlines the operational details of the pH tests at 7.0 and 7.85. For the tests carried out at pH levels above 7.85, the filter runs were extremely long. Therefore, the turbidity tests and projected filter times were determined for several pH values during the same filter run. This is why there is no headloss data available for the filter runs at 8.2 and 8.85 pH units in Appendix 8.

The results indicate that the pH is of primary importance in establishing the filter performance, particularly near

a pH of 8.0 units. A treated water pH in excess of 8.0 units results in a dramatic increase in length of filter runs and a deterioration of effluent quality.

It was also found that length of filter runs corresponded with a decrease in insoluble aluminum (Table 15). Between a pH of 7 and 7.85, there is little change in either length of filter run or effluent quality despite the fact that a much higher percentage of aluminum is in solution at a pH level of 7.85. This fact suggests that the physical characteristics of the floc formed over the pH range of 7 to 8 are relatively constant but the chemical composition of the floc must change considerably with the change in pH.

TABLE 15

FILTER PERFORMANCE VS ALUMINUM LEVELS

(1.05 mm Coal)

Filter Rate - 6 Igpm/sq ft

Alum Dose - 6 mg/l

Al Dose - 0.55 mg/l

Floc Gradient - 20 sec^{-1}

Floc Time - 14.5 min

Run Number	Residual Al mg/l	Insoluble Al mg/l	Run Time hr	Eff. Water pH
30	0.03	0.52	23.0	7.0
29	0.24	0.31	26.5	7.85
31	0.50	0.05	110*	8.2
31	0.53	0.02	280*	8.85

*Projected from Head Loss Rate of Increase

4 COADULANTS

GENERAL

Most of the plants in Ontario, including all of the direct filtration plants use alum as the primary coagulant. Our initial tests were carried out to determine the limitations of alum when used for direct filtration.

Ferric chloride was also studied because of the superior floc strength characteristics exhibited in previous pilot clarifier tests [13]. Ferric chloride has had limited use in Ontario because of its high cost and the uncertainty of a steady supply. In recent months, ferric chloride has become more readily available in Ontario.

The use of polymers as coagulants was attractive because of the extremely small floc volume characteristics that they offer.

The use of alum alone in direct filtration is limited by the frequency of filter breakthrough particularly from the larger filter coal sizes and at the high filtration rates.

There were no filter breakthrough problems with ferric chloride under conditions where alum alone was known to be inadequate. This implies that the ferric chloride floc is stronger than the alum floc and may be more suitable for direct filtration.

The polymers studied were found to be effective in reducing the alum demand but were unable to replace the alum requirements completely.

4.1 Alum

Most data confirm that the floc volume is proportional to the coagulant dosage used when the floc is formed under similar conditions [14]. The fact that the floc does not significantly compact during the filtration process results in a direct relationship between coagulant dosage and length of filter runs.

4.1.1 Filtration Rate - 4.0 Igpm/sq ft

The current maximum filtration rate allowed by the Ministry of the Environment is 4.0 Igpm/sq ft. Because of this, the first series of tests were carried out at this rate to establish an alum dosage - filter run time relationship. This relationship is outlined in Figure 11.

FIGURE 11

ALUM DOSAGE vs FILTER TIME

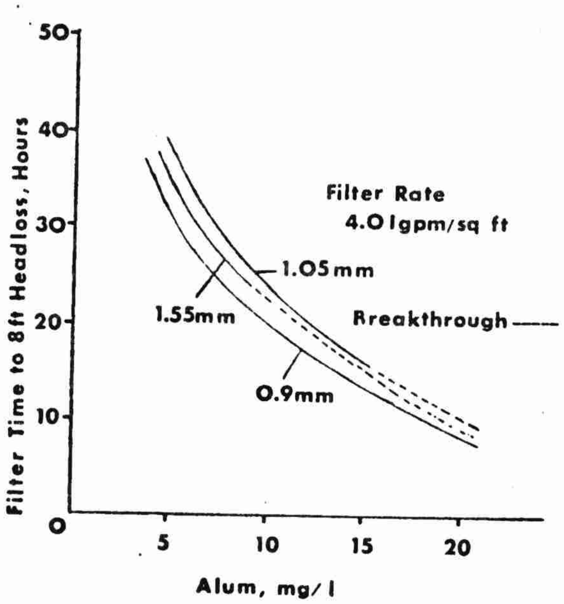
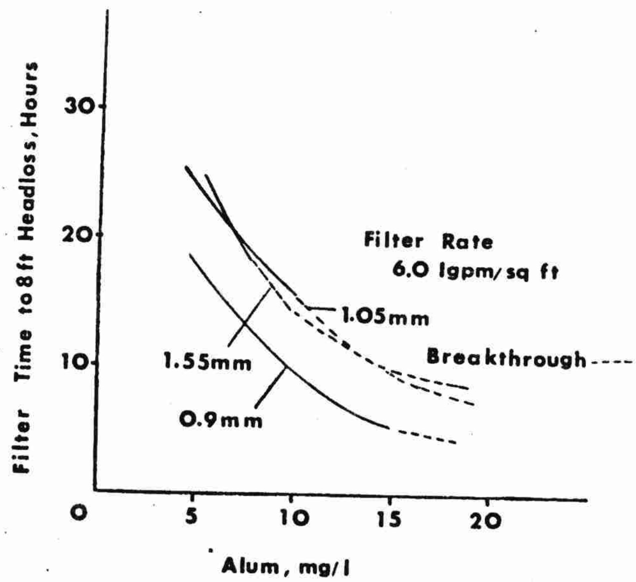


FIGURE 12

ALUM DOSAGE vs FILTER TIME



All filter runs were terminated at 8 feet of headloss. If breakthrough occurred prior to terminal headloss, the length of filter runs was calculated from projecting the rate of increase of the headloss to 8 feet. Filter breakthrough was experienced with the 1.55 mm coal and with the 1.05 mm coal at alum dosages in excess of 10 mg/l and 15 mg/l respectively. Alum dosages less than 3.8 mg/l led to an effluent turbidity in excess of the 0.3 Ftu objective.

Filter Time

A review of Figure 11 indicates that the lengths of filter runs for the 0.9 mm coal are considerably shorter than those for the 1.05 mm and the 1.55 mm coals. The floc did not penetrate the 0.9 mm coal to the same extent as it did with the coarser coals. This partial penetration resulted in a reduced utilization of the available floc deposition sites within the filter bed and thus shorter filter run times.

The run times for the 1.05 mm and the 1.55 mm coals are similar but for different reasons. The floc penetration of the 1.05 mm coal was greater than that of the 0.9 mm coal. As a result, there was a greater use of the storage space within the coal layer and the coal-sand interface area. The larger storage capabilities of the filter coal led to longer filter runs. The filter reached terminal headloss mainly due to a clogging of filters in both the coal and sand layers.

The filter containing the 1.55 mm coal showed an even greater dependence on the lower regions of the filter bed to retain the floc. The filter reached 8 ft of headloss primarily

due to a clogging of the filter bed in the coal-sand interface regions and not due to exhausting available deposition sites in the coal layer. For this reason it is expected that coal larger than 1.55 mm would lead to even shorter filter runs. This would be due to a higher dependence on the lower regions to trap the floc and the filter bed would be approaching that of a single sand layer. It is realized that algae, floc strength, and other related factors can alter these conclusions. The influence of algae is discussed in Section 4.1.3.

Under the conditions specified, the optimum coal size in terms of length of filter run and absence of filter break-through would lie close to the 1.05 mm effective size coal.

Typical detailed results from an alum only feed system are listed in Appendix 9 for filtration rates of 4 Igpm/sq ft. The alum feed varied from a low of 3.8 ppm to a maximum of 40 ppm. The run with an alum dosage of 40 ppm was an instance of chemical over-dosing in comparison to the turbidity level. However this example clearly indicates the extremely short filter runs that result at these high coagulant dosages. This filter performance would be typical of colour removal plants where low-turbidity, high-colour water is prevalent.

4.1.2 Filtration Rate - 6.0 Igpm/sq ft

Several filter runs were carried out to determine filter performance in a direct filtration application at rates of 6.0 Igpm/sq ft. These high filter rates are predicted for use in the future for facilities where sedimentation is included. The length of filter runs for a direct filtration system under adverse conditions at 6.0 Igpm/sq ft becomes an important consideration in determining the final design of the system.

Figure 12 outlines the relationship between the filter time to 8 ft of headloss and alum dosage. Without the use of a filter aid, breakthrough took place in the 1.55 mm coal and the 1.05 mm coal at 7.5 mg/l and 10.5 mg/l of alum respectively. For the 0.9 mm coal, alum dosages above 15 mg/l led to breakthrough problems. As was the case at the lower filtration rates alum dosages less than 3.8 mg/l led to an effluent turbidity in excess of 0.3 Ftu.

As expected, the lengths of filter runs at 6.0 Igpm/sq ft are shorter than those at 4.0 Igpm/sq ft. The gross water production per foot of headloss increase is greater for the lower filtration rate than at 6.0 Igpm/sq ft. It is known that the shearing forces on the floc within the filter bed are increased as the filtration rate is increased. These higher shearing forces reduce the available number of floc deposition sites and the total water production is reduced proportionally. Dostal and Robeck[15,16] have had similar findings.

As was found at 4.0 Igpm/sq ft., the lengths of filter runs for the 0.9 mm coal are considerably shorter than those of

the 1.05 mm and the 1.55 mm coals. The reasons for this are felt to be the same as those discussed in section 4.1.1.

The results of the floc distribution and operating characteristics for some of the filter runs plotted on Figure 12 are included in Appendix 10.

4.1.3 Algae Influence

One of the main difficulties in stating the length of filter run for a particular media under a given set of conditions is the influence of filter clogging algae. High levels of diatoms are discussed in detail in Section 3.2. Algae levels, particularly diatoms, can have a strong influence on the length of filter runs even at levels below 400 Asu/ml especially if the effective size of the filter media is less than 1.2 mm. This fact should be recognized particularly when comparing filter performance at various times throughout the year. Table 16 (details in Appendix 11) highlights the differences in filter performance at algae levels normally referred to as low.

TABLE 16

Effect of Low Algae Levels on Filter Performance

Run	Coal e.s. mm	Run Length to 8' H.L. hrs	Headloss Distribution Coal %	Sand %	Algae Asu/ml
4	0.9	25.5	85	15	300
	1.05	37.5	56	44	300
	1.55	45.5	26	74	300
23	0.9	40	71	29	70
	1.05	43	40	60	70
	1.55	50	25	75	70

Filter Rate 4 Igpm/sq ft
Alum 6 ppm

For the 0.9 mm e.s. coal the filter run was 40 hours with the algae level less than 70 Asu/ml. As the algae level increased to 300 Asu/ml, the filter runs decreased to 25.5 hrs. Similarly, the 1.05 mm e.s. coal filter run reduced from 43 hours to 37.5. The 1.55 mm e.s. coal which allowed a greater penetration of the diatoms into the filter bed was relatively unchanged in operating time. The headloss distribution for these coal sizes indicate that the diatoms are trapped in the filter coal.

A simplified method of determining what the average diatom count was during the course of a filter run is to take a representative sample of the backwash water and perform an algae count on it. The possibility of unrepresentative grab samples taken on the raw water can be overcome in this manner.

4.2 Ferric Chloride

The use of iron salts as coagulants in the purification of turbid waters began shortly after the turn of the century[17]. Plant studies have indicated that ferric chloride dosages range from 30-60 percent of the alum requirements [17,18,19,20]. Studies carried out by Research Branch personnel indicated that ferric chloride, if introduced as a coagulant at the proper pH, would produce a strong, heavy floc superior to alum[13]. The attractiveness of this apparently superior floc strength prompted the study. Another aspect of the ferric chloride is its insolubility in water at higher pH values. The raw water pH of Lake Huron remains above 8.1 much of the year. The ferric chloride iron residual remains below 0.05 mg/l with raw water pH levels exceeding 8.1 units. The chemical aspects of ferric

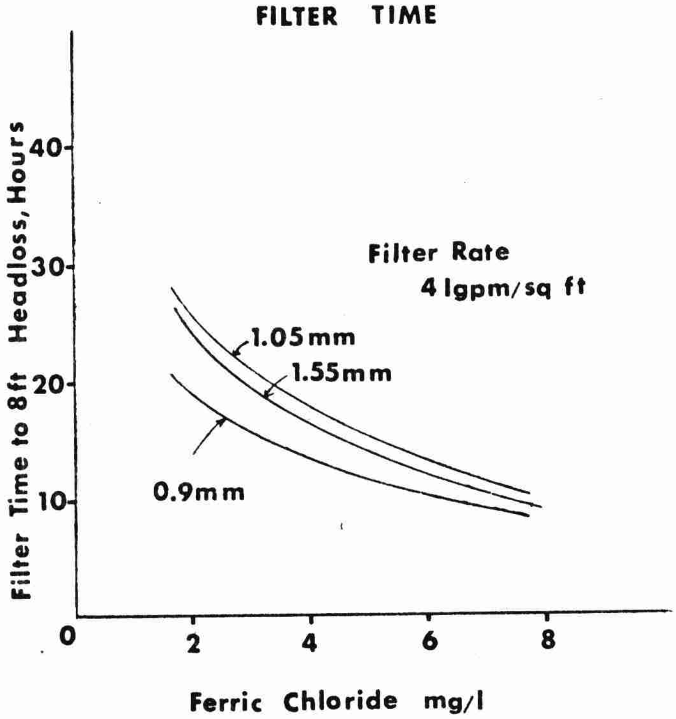
chloride in aqueous solution are outlined in detail by W. Stumm and J.J. Morgan [21]. The physical characteristics of ferric chloride treatment in plant scale basins is also well documented [19,20].

4.2.1 Pilot Plant Study

The relationship between the ferric chloride dosage and length of filter runs for the 0.9, 1.05 and 1.55 mm e.s. coal at 4 Igpm/sq ft is illustrated in Figure 13.

FIGURE 13

FERRIC CHLORIDE DOSAGE vs FILTER TIME



The complete results of the ferric chloride work are listed in Appendix 12 and the Appendix Supplement.

As discussed in section 4.1, the floc volume is the governing factor in determining the length of filter run. The minimum dosage of ferric chloride tested was 1.75 mg/l with good effluent quality. Even with ferric chloride dosages as high as 6.7 mg/l there was no recorded instance of filter breakthrough. The raw water pH remained at 8.3 and the iron residual for all filters was less than 0.05 mg/l for all tests. Ferric chloride dosages of 1/3 to 1/2 those of alum were required to obtain the same effluent quality and overall filter performance.

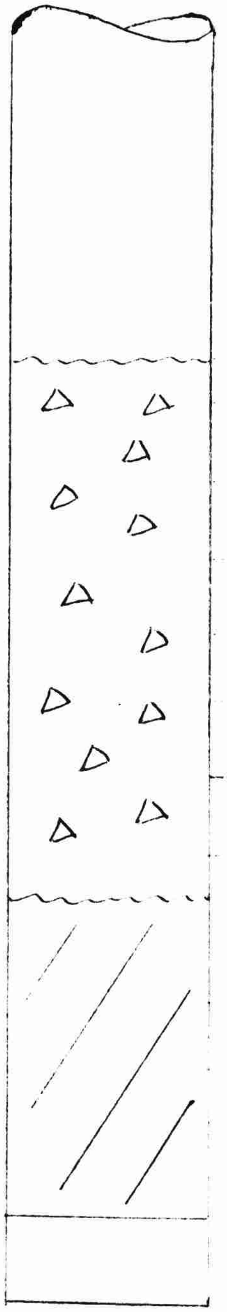
Floc Distribution

Table 17 outlines the floc distribution within the filter bed for the 0.9 mm and the 1.55 mm effective size coal filters. Approximately equivalent dosages of alum and ferric chloride on a metal ion basis were made. That is, 4.3 mg/l of ferric chloride versus 13.6 mg/l alum. The headloss distributions show the ferric floc was trapped higher in the filter bed than the alum floc for both filter coals. Based on previous experiments and conclusions, this implies that the iron floc is stronger than an equivalent amount of alum floc.

TABLE 17

HEAD LOSS DISTRIBUTION RESULTS

Ferric Chloride and Alum



Filter Depth inches					
	Run #	48	48	52	52
	Coal Size mm	0.9	1.55	0.9	1.55
	$FeCl_3$ mg/l	4.3	4.3	0	0
	Alum mg/l	0	0	13.6	13.6
34	Head Loss %				
33		49.9	18.2	23.8	12.2
30		28.7	20.3	23.1	14.4
27		7.6	12.0	14.4	7.7
24		1.9	7.9	8.4	5.5
21		1.0	5.6	5.2	5.0
18		0.8	5.3	2.8	6.5
15		-	6.3	-	14.4
12		0.2	13.9	8.7	18.0
9		1.3	4.4	8.0	8.1
6		4.8	1.4	4.7	2.7
4		2.3	1.9	0.8	3.3
0		1.5	2.8	0.1	2.2

Filtration Rate - 4 Igpm/sq ft
Flocculation Gradient - 20 sec^{-1}

4.2.2 Plant Study

A three day ferric chloride study was carried out at the Lake Huron Water Supply System at Grand Bend from June 24 through June 27, 1974.

The results of this plant scale study are listed in Table 18.

TABLE 18
Plant Scale Tests with Ferric Chloride

$FeCl_3$	4 ppm
Alum	8 ppm

		Raw	$FeCl_3$ Filters	Effluent Alum Filters	Plant
Turbidity	Ftu	5.0	0.4	0.5	0.45
pH		7.9	7.62	7.59	7.50
Iron	ppm	0.03	0.05	0.02	0.03
Aluminum	ppm	0.0	0.04	0.12	0.07

Filtration Rate (Ave.) - 1.5 Igpm/sq ft

Half of the plant was run using 8 mg/l alum as the sole coagulant while 4 mg/l ferric chloride was the only coagulant on the other half of the plant. The results indicate that where the ferric chloride is used the iron residual is slightly higher but the effluent turbidity is slightly lower. An aluminum residual in the filtered water persisted for several days from the ferric chloride half of the plant. This was probably due to the remnants of the alum floc remaining in the flocculation basin.

The filters where alum was the only coagulant had an aluminum residual range of 1.10 to 0.15 mg/l and an average of 0.12 mg/l throughout the test period. The effluent pH was similar to that of the ferric chloride filters and the overall plant effluent.

The aluminum residual leaving the plant varied from 0.14 mg/l at the beginning of the tests to 0.06 mg/l during the third day. The iron residual in the plant effluent varied from an early test high of 0.12 mg/l to 0.03 mg/l during the second and third test days.

The length of filter runs was similar for the ferric chloride and the alum coagulated waters. Plant scale tests lasting 2 months were carried out in August 1974 in order to keep the aluminum residual leaving the plant to below 0.1 mg/l when the raw water pH was above 8.1.

4.3 Polymers

Apart from the algae loading, the single most important factor governing the length of filter run to terminal headloss is the floc volume. The large volumes associated with alum and ferric chloride floc result in filter runs that are unacceptably short at the higher filtration rates.

The growing number of water soluble cationic, synthetic and modified natural polymers have shown in many instances an ability to successfully replace alum as the prime coagulant. The dosages required are usually a small fraction of those of alum or iron coagulants. Their floc volume is significantly

lower than the metal salts and because of this, it is felt that longer filter runs should result. Crook and Pollio[22] have successfully treated the Delaware River water using a cationic polymer as the only coagulant. Pressman [23] concluded that a cationic polyelectrolyte of the poly-quaternary ammonium type can serve effectively as a prime coagulant, replacing a metal salt, for the treatment of natural water in a solids contact clarifier and pressure - diatomite filter system. Other workers have also successfully experimented with polymers as the only coagulant[24].

A reduction in the sludge volume can be of great help in handling, treating and disposing of the wastes. The advantages of polymer wastes and wastes treated with polymers have been tabulated by Doe[25] and Gates [26].

4.3.1 <u>Theory</u>

The mechanism for the destabilization of colloids by polymers has been well reviewed by both Singley[27] and Shea[28]. Singley schematically illustrated the adsorption mechanism and the subsequent interaction of the polymer particles with a colloid particle. To work properly the polyelectrolyte should attach itself to the colloid particle and extend the polymer chain out into the bulk of the solution. These extended chains should interact either with other extended chains or other particles. If sufficient charge neutralization of the particles by the polymer takes place, particle agglomeration should result. The agglomerated particle then can be settled or as is the case in direct filtration, be placed directly on to the filter.

As Singley points out, if the polymer chains fail to interact with other particles in solution, the polymer chain may wrap itself around the destabilized particle and prevent proper agglomeration. This may lead to a particle with poor removal characteristics by sedimentation or filtration facilities.

4.3.2 Cationic Polymer
<u>Pilot Filter Results</u>

A summary of the work carried out in Sarnia with the pilot plant is listed in Tables 19 and 20. Appendix 13 continues the completed set of results.

TABLE 19

CATIONIC POLYMER FEED

1.05 mm e.s. Coal

Run #	Filter Rate	Malcolyte 607	Run Time	Final Head Loss	Turbidity Raw	Turbidity Eff.
	Igpm/ sq ft	mg/l	hr	inches	Ftu	Ftu
19	4	0.2	50.0	36.0	1.5	0.50
26	4	0.4	23.5	19.0	1.7	0.90
28	2	0.4	73.0	14.0	1.8	0.70
42*	4	0.3 av.	43.5	20.0	0.8	0.45
43	4	0.3**	21.0	17.0	1.2	0.50
12	4	5.7***	38.0	85.0	1.8	0.22
			1.55 mm e.s. Coal			
19	4	0.2	50.0	26.0	1.5	0.50
26	4	0.4	23.5	16.5	1.7	0.90
28	2	0.4	73.0	8.8	1.8	0.70
43	4	0.3**	21.0	18.0	1.2	0.50
12	4	5.7***	37.0	96.0	1.8	0.20

Flocculation Velocity Gradient - 20 sec^{-1}
Flocculation Time - 18 min

*Flocculation Velocity Gradient - 550
Flocculation Time - 11 min

**Cationic Polymer B

***Alum

Table 19 indicates the findings using Nalcolyte 607 as the primary coagulant. A review of the results shows the difficulty in obtaining effluent levels when using Nalcolyte 607 alone (equivalent to those using alum). During many of these tests, the polymer was shut off (for periods up to 10 hours) with little or no deterioration in effluent quality. Similar findings resulted when Nalcolyte 8101 was used.

The effluent turbidity did not appear to be dependent on:

- the filter coal size
- the filtration rate
- the polymer dosage
- the flocculation velocity gradient

The effluent turbidity appeared to be dependent on the raw water turbidity. For all tests the rate of increase in the headloss was extremely low. Only string-like floc was periodically visible.

4.3.3 High Velocity Gradient Test

The mean velocity gradient G is given as:

$$G = (P/\mu V)^{\frac{1}{2}}$$

where P = power dissipated in the water (ft lb/sec)

V = volume of tank or basin to which the power is applied (cu ft)

μ = absolute viscosity of the water (lb/sec/sq ft)

Following the findings of Morrow and Rausch [29] where high velocity gradients (G) were used to obtain good effluent quality, test 42 (Table 19) was carried out. The three stage flocculation section had G values in the order of 800 sec^{-1}

for 3 minutes, 700 sec^{-1} for 4 minutes and 200 sec^{-1} for 4 minutes. The results indicate that the G value had little to do with the effluent turbidity for this particular polyelectrolyte. The control test with alum as the coagulant (Run #12) shows the shorter run time but improved effluent turbidity characteristic.

4.3.4 Polymer Plus Alum Pilot Filter

Table 20 outlines the results obtained after running comparative tests with alum plus Nalcolyte 607 and 8101 against alum only with a constant raw water turbidity of 40 Ftu for a coal size of 1.05 mm.

TABLE 20

ALUM PLUS CATIONIC POLYMER TESTS

1.05 mm e.s. Coal

Alum mg/l	Eff. Turb. Ftu	Alum + mg/l	Nalcolyte 607 mg/l	Eff. Turb. Ftu	Alum + mg/l	Nalcolyte 8101 mg/l	Eff. Turb. Ftu
					0	0.4	3.4
					0	0.8	3.0
3.0	10+	3.0	0.38	2.1	3	0.4	2.1
3.95	7.5						
5.0	2.3	5.0	0.38	0.71	5	0.4	1.4
		5.5	0.38	0.43	6	0.4	0.77
7.0	1.0	7.0	0.38	0.23			
9.1	0.29				9	0.4	0.18
11.0	0.22	5.1	0.26	1.0			
12.2	0.21						
15.0	0.23						

Filtration Rate - 4 Igpm/sq ft

Flocculation Velocity Gradient - 20 sec^{-1}

Flocculation Time - 18 min

Raw Water Turbidity - 40 Ftu

The results indicate that the effluent turbidity at a dosage of 10 mg/l of alum was readily obtained with 7 mg/l alum plus 0.38 mg/l of the Nalcolyte 607. Although many other similar observations can be made from this chart, the most significant fact is that substantial reductions of alum can be realized when alum is used with the Nalcolyte 607. Similar results were found for the other coal size and for Nalcolyte 8101.

4.3.5 Cationic Polymer Plant Results

Table 21 is representative of the results obtained during a 2 month study (August and September) using the Lake Huron Water Supply System full scale facilities.

TABLE 21

LAKE HURON SUPPLY SYSTEM RESULTS

Filtration Rate	Filter Coal Eff. Size	Nalcolyte 607	Turbidity Raw	Turbidity Eff.
Igpm/sq ft	mm	mg/l	Ftu	Ftu
0.6	1.5	0.3	4.4	1.5
1.2	1.0	0.3	4.4	1.3
0.6	1.5	0.6	31.0	3.3
1.2	1.0	0.6	31.0	3.2
2.5	1.5	0.3	1.1	0.56
2.5	1.0	0.3	1.1	0.62

Alum Dose - 0 mg/l

Flocculation Velocity Gradient - 15 sec^{-1}

Flocculation Time - 100 min

Nalcolyte 607 by itself was not able to keep the filter effluent below 1.0 Ftu when the raw water turbidity exceeded 3.0 Ftu. As was the case with the pilot filters, the effluent turbidity did not appear to be dependent on the filtration rate, the filter coal effective size or the flocculation intensity. The polymer appears to be more effective at reducing turbidity when the raw water turbidity is high (e.g. 31 Ftu reduced to 3.3 Ftu).

Polymer plus Alum Plant Results

Good results have been obtained with the combination of Nalcolyte 607 plus alum. Using Table 22 as a coagulant dosage guideline, comparable effluent turbidities were obtained when one half of the plant was fed alum only while the other half was fed polymer plus a reduced amount of alum.

TABLE 22

LAKE HURON WATER SUPPLY SYSTEM

Coagulant Dosage Guide

September, 1973

SOUTH FILTERS			NORTH FILTERS	
Raw Turbidity Ftu	Alum	Cationic Polymer mg/l	Raw Turbidity Ftu	Alum mg/l
< 5	5	0.1	< 5	7
5 - 10	6	0.2	5 - 10	10
10 - 20	7	0.2	10 - 20	12
20 - 40	8	0.2	20 - 40	15
40 - 60	8	0.3	40 - 60	17
60 - 100	9	0.3	60 - 100	20
100+	10	0.3	100+	20

The lengths of filter runs are increased for the Nalcolyte 607 - alum combination. This alum reduction may play an important role for future direct filtration plants with projected filtration rates equal to or greater than 4 Igpm/sq ft. If the alum could be reduced significantly, it would also greatly aid the operation of future plants when they are subjected to raw water conditions that demand high alum dosages. A cationic polymer has also lowered the alum required in a water plant in England [30]. The alum demand was reduced there from 40 mg/l to 24 mg/l with only 0.008 mg/l of a cationic polymer being used.

The Lake Huron Water Supply System is retaining some of the Nalcolyte 607 for tests during periods of high turbidity to alleviate the alum demands.

4.3.6 Flocculation - Filtration Test (Polymer Alone)

After discussion with polymer manufacturers' representatives a test was carried out to determine the effect of adding a cationic polymer directly above the filter media. This process is called contact flocculation - filtration and has been used successfully by Adin and Rebhun [31]. It was hoped that a successful adaptation of this technique would allow the polymer to be fed by itself on a continuous basis to produce an acceptable effluent.

The results of testing the Nalcolyte 607 and Catfloc T cationic polymers are given in Figure 14. Catfloc T has been used with alum on a jar test basis and had proved

to be successful in reducing the alum demand close to 60 percent.

FIGURE 14

POLYMER as a PRIMARY COAGULANT

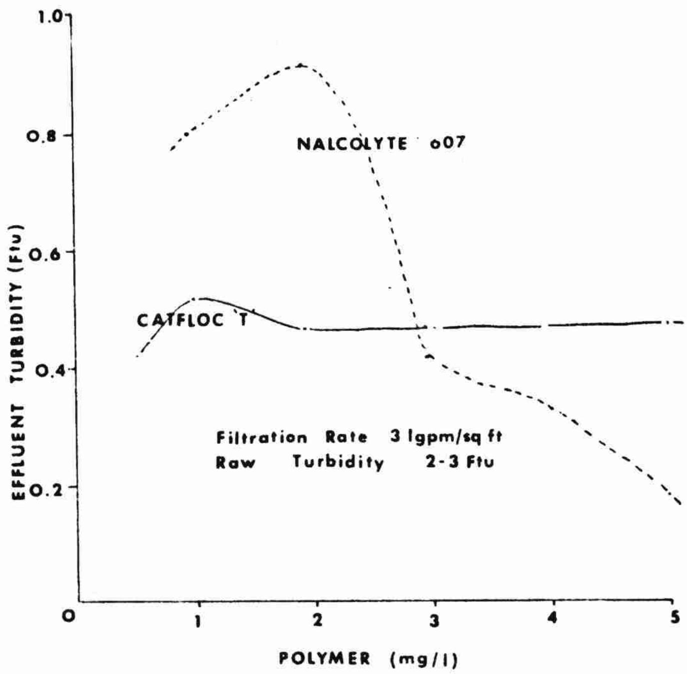


Figure 14 indicates that to produce an acceptable effluent quality, 4 ppm of Nalcolyte 607 would have to be used. Catfloc T on the other hand did not reduce the turbidity to an acceptable level. No problems occurred with either of the polymers in backwashing the filters. Pilot plant personnel working on direct filtration for Metro Toronto[32] experienced agglomeration of high density floc which required backwash times of an hour or more.

More work is needed to study the minimum addition of polymer to obtain an acceptable effluent. The effect of feeding

the polymer in this manner under high raw water turbidity conditions should also be investigated.

5 MIXING

General

The importance of both flash mixing and flocculation for plants using sedimentation facilities has been well reviewed [33,34].

It has been the practise of most authors to present their mixing data using the velocity gradient term G as developed by Camp. The mean velocity gradient G given by Camp was defined in Section 4.3.3.

Work was carried out to study the effect of the velocity gradient on the filter performance for both the flash mix and the flocculation mixing sections. In addition, the flocculation time was studied.

The results indicate that the higher flocculation G values can create breakthrough problems. In addition the probability of filter breakthrough increases as the flocculation time increases. The best results were obtained using flocculation times of less than 10 minutes. The flash mix intensity (G values less than 600 sec^{-1}) has little effect on the overall filter performance.

5.1 Flash Mixing

Camp studied the impact of rapid mixing on floc formation [33]. He reported that mixing at G values of 500 sec^{-1} to 1000 sec^{-1} for about 2 minutes produced essentially complete coagulation and prolonged rapid mixing at this intensity accomplished practically nothing more. Hudson and Wolfner [35] outlined the rapid mixing design criteria and stated that practice in design has been to use not more than 30 seconds in a rapid mix section.

Flash Mix Results

Our findings on the importance of the flash mix section to direct filtration are outlined in Tables 23,24, Appendix 14 and Supplement.

TABLE 23

FLASH MIX STUDY

Run Number	Filter Coal Eff.Size	Filter Rate	Alum	Turbidity Raw	Turbidity Eff.	Run Time
	mm	Igpm/ sq ft	mg/l	Ftu		hr
37	0.9	6	6.0	1.5	0.18	23.5
35*	0.9	6	5.5	1.5	0.16	24.0
38	0.9	4	10.0	12.0	0.12	19.0
39*	0.9	4	10.0	12.0	0.23	19.0
37	1.05	6	6.0	1.5	0.20	27.0
35*	1.05	6	5.5	1.5	0.20	29.0
38	1.05	4	10.0	12.0	0.17	23.0
39*	1.05	4	10.0	12.0	0.23	25.0
37	1.55	6	6.0	1.5	0.20	29.0
35*	1.55	6	5.5	1.5	0.16	31.0
38	1.55	4	10.0	12.0	0.12	23.5
39*	1.55	4	10.0	12.0	0.23	24.5

*No Flash Mix

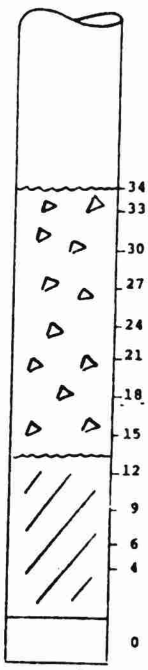
Flocculation Velocity Gradient - 20 sec^{-1}

Flocculation Time - 18 min

TABLE 24

HEAD LOSS DISTRIBUTION RESULTS

Flash Mix Study



Run #	37	35	38	39
Coal Size mm	1.05	1.05	1.05	1.05
Flash Mix	Yes	No	Yes	No
Alum mg/l	6	5.5	10	10
Head Loss %				
	24.7	25.2	19.9	26.0
	14.9	14.6	20.3	23.8
	8.2	8.6	12.5	10.2
	4.7	5.8	5.8	6.0
	1.7	2.2	3.1	3.3
	-	-	-	-
	5.6	3.7	3.5	2.2
	14.9	13.5	21.8	8.5
	14.8	19.9	9.5	11.0
	8.6	3.2	1.8	2.4
	0.2	1.8	1.1	1.2
	1.7	1.5	0.7	5.4

Filtration Rate (Run # 35, 37) - 6 Igpm/sq ft
(Run # 38, 39) - 4 Igpm/sq ft

Flocculation Gradient - 20 sec^{-1}

The work was carried out under low raw water turbidity conditions ($<$ 2 Ftu) and at a high filtration rate of 6 Igpm/sq ft as well as at a turbidity level of 12 Ftu and a filtration rate of 4 Igpm/sq ft. The flash mix velocity gradient was 500 sec^{-1} and the flash mix time was approximately 2 minutes. All runs were terminated at a headloss in excess of 8 feet. The filter performances are similar in terms of length of filter run and headloss distribution. There is a slight improvement in effluent quality for Run #38 (with flash mix) over Run #39 (no flash mix).

5.2 Flocculation Velocity Gradient

As stated earlier, the floc volume plays an important role in determining the length of the filter run. Previous work has indicated that the floc volume is proportional to the coagulant dosage, all other factors being equal. Camp has indicated that the floc does not compact during the filtration process[36].

Reducing Floc Volume

It is known that some mechanism must be devised for reducing the floc volume if longer filter runs are to be obtained. Hudson [37] showed that the volume of floc is much greater for low-agitation speeds than for high-agitation speeds, the difference being as great as 25-fold. It follows that the more compact floc produced at the high flocculation velocity gradients should reduce the work of the filters and prolong the length of filter runs.

Previous work at filtration rates of 6 Igpm/sq ft indicated that the flocculation velocity gradient played an important

role in determining headloss distribution [38]. Some of the findings of these tests are listed in Tables 25 and 26.

TABLE 25

FLOCCULATION VELOCITY GRADIENT STUDY

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Floc Gradient	Run Time
	mm	Ftu	Ftu	sec^{-1}	hr
S-13	0.9	0.8	0.17	20	9.0
S-16	0.9	0.7	0.10	50	10.5
S-13	1.05	0.8	0.18	20	13.0
S-16	1.05	0.7	0.10	50	13.0
S-13	1.55	0.8	0.18	20	13.0
S-16	1.55	0.7	0.10	50	12.5

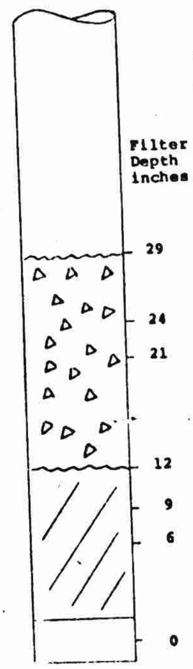
Filtration Rate - 6 Igpm/sq ft

Alum - 10 mg/1

TABLE 26

HEAD LOSS DISTRIBUTION RESULTS

Flocculation Velocity Gradient Study



Filter Depth inches	Run #	S-13	S-16	S-13	S-16
	Coal Size mm	0.9	0.9	1.55	1.55
	Floc G sec^{-1}	20	50	20	50
	Head Loss %				
29		80.0	63.9	23.6	16.6
24		8.2	9.6	9.4	6.2
21		6.6	10.6	22.4	19.0
12		4.9	11.8	35.3	43.1
9		0.1	1.8	8.1	8.4
6		0.2	2.3	1.2	6.7
0					

Filtration Rate - 6 Igpm/sq ft
Alum - 10 mg/1

Floc Distribution

In order to study the floc distribution at varying G levels under medium alum dosages, 10 mg/1 of alum was used; this was higher than that required to obtain the 0.3 Ftu objective. The results of the two tests are outlined in Table 25 (Appendix 15 and Supplement).

The headloss distribution (Table 26) for these tests shows a deeper filter bed penetration of the floc at the higher G values. Later tests (Table 27), where the correct alum dosage for the raw water turbidity conditions to meet the 0.3 Ftu objective was added, indicated that the shift in headloss distribution for different flocculation G values was not as great as was indicated by Table 26. Nevertheless, the probability for filter breakthrough appears to be increased as the flocculation G is increased. It is suspected that the increase in mixing intensity produces an increased number of very small floc particles. These floc particles are deposited deep within the filter bed, probably into the sand layer. Their rate of accumulation is faster than with conventional flocculation gradients of 10 to 20 sec^{-1}. As a result, breakthrough can occur at a lower headloss.

With higher coagulant dosages and subsequently a greater number of floc particles being deposited at all levels throughout the filter bed, breakthrough occurs in a similar manner to that found for the higher velocity gradient. The key to breakthrough appears to lie in the rate of accumulation of the floc particles on to the sand layer. This hypothesis excludes floc strength which is an unknown variable for these tests. It is felt that a greater amount of weaker floc is present for the higher coagulant dosage simply because of the greater amount of floc in general.

High Flocculation G Values

Table 27 (and Appendix 16) outlines further tests where the correct alum dosage was added for the turbidity conditions listed.

TABLE 27

FLOCCULATION VELOCITY GRADIENT STUDY

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Floc Gradient	Final Head Loss	Run Time
	mm	Ftu		sec^{-1}	ft	hr
53	0.9	16.0	0.14	20	8+	16.0
54	0.9	12.5	0.14	100	8+	15.0
55	0.9	14.0	0.14	300	7.3*	17.0
53	1.05	16.0	0.15	20	6.0*	14.5
54	1.05	12.5	0.13	100	6.0*	16.5
55	1.05	14.0	0.15	300	4.5*	13.0
53	1.55	16.0	0.13	20	6.0*	13.5
54	1.55	12.5	0.15	100	6.0*	13.5
55	1.55	14.0	0.15	300	4.5*	11.5

Filtration Rate - 4 Igpm/sq ft

Alum - 12 mg/l

Flocculation Time - 14.5 min

*Filter Breakthrough

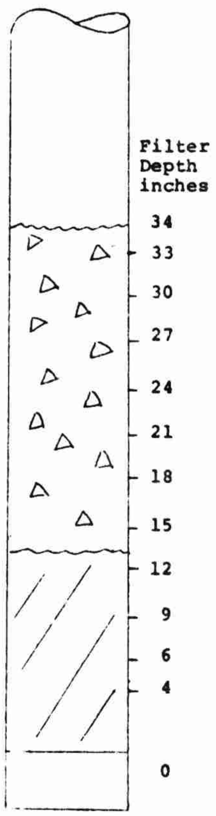
The findings indicate that with the higher flocculation velocity gradients there is an increased likelihood of filter breakthrough. However, with the higher G value there is a

reduced floc volume. This is evidenced by a lower rate of increase in the headloss in those runs where a higher G value was used. This is why, in some instances, the filter broke through at a lower headloss but had a long filter run time. The headloss distribution for these runs is given for the 1.05 mm e.s. filter coal in Table 28 (Appendix 16).

TABLE 28

HEAD LOSS DISTRIBUTION RESULTS

Flocculation Velocity Gradient Study



Run #	53	54	55
Coal Size mm	1.05	1.05	1.05
Floc G sec^{-1}	20	100	300
Head Loss %			
	17.0	24.2	18.1
	14.9	15.5	12.2
	9.4	8.9	8.0
	6.9	5.8	6.1
	5.3	4.6	6.1
	3.4	3.1	3.3
	2.1	2.7	2.1
	13.4	15.7	12.7
	11.3	8.5	19.0
	5.5	6.7	6.3
	7.6	2.5	2.1
	3.2	1.8	4.0

Filtration Rate - 4 Igpm/sq ft
Alum - 12 mg/l
Flocculation Time - 14.5 min

There appears to be no significant shift of the headloss distribution for these tests. Similar results were found for the 0.9 mm e.s. coal and the 1.55 mm e.s. coal filters.

Appendices 17 through 20 outline other flocculation velocity gradient tests that were carried out in 1972, 1973 and the winter of 1974. The flocculation velocity gradient of 300 sec^{-1} (Appendices 16 & 17) leads to filter breakthrough at a lower headloss than that when a G value of 20 sec^{-1} is used. Again, the rate of headloss increase is lower because of the smaller floc volume produced by high speed mixing. For flocculation velocity gradients of 20 to 100 sec^{-1} (Appendices 18 - 20), the overall effect on filter performance (filter time and breakthrough) appears to be less significant than those results at a G value of 300 sec^{-1}.

5.3 Flocculation Time

Most researchers and plant personnel suggest that the absolute minimum for the flocculation time required by sedimentation systems is twenty to thirty minutes [35,39]. The necessity of a heavy floc for the sedimentation process is probably the underlying factor for this.

Flocculation times ranging from 4.5 to 28 minutes were studied. Because of the non-ideality of flow in the flocculation basin [40], all retention time data were determined experimentally using a tracer.

5.3.1 Flocculation Time Pilot Plant Study 1972

The first set of experiments to determine the effect of flocculation time on filter performance was carried out in the fall of 1972. Three retention times of 8.0, 14.5 and 18 minutes were tested at a filtration rate of 6 Igpm/sq ft. The operating results are listed in Table 29. Filter breakthrough took place at a progressively lower headloss as the flocculation time was increased beyond 8 minutes. The rate of headloss increase and filter effluent quality were similar for all filter runs.

A typical headloss distribution for the 1.05 mm e.s. coal for all four filter runs is outlined in Table 30 (Appendix 21).

TABLE 29

FLOCCULATION TIME STUDY - 1972

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Floc Time	Final Head Loss	Run Time
	mm	Ftu		min	ft	hr
S-26	0.9	7.0	0.18	8.0	8+	8.7
S-28	0.9	4.5	0.15	14.5	8.0*	8.8
S-24	0.9	19.0	0.20	14.5	5.6*	5.8
S-25	0.9	18.0	0.19	18.0	4.2*	4.5
S-26	1.05	7.0	0.18	8.0	8+	10.0
S-28	1.05	4.5	0.15	14.5	5.5*	6.2
S-24	1.05	19.0	0.21	14.5	4.0*	5.2
S-25	1.05	18.0	0.19	18.0	3.6*	4.2
S-26	1.55	7.0	0.18	8.0	8+	9.5
S-28	1.55	4.5	0.20	14.5	4.8*	6.0
S-24	1.55	19.0	0.25	14.5	3.0*	3.6
S-25	1.55	18.0	0.23	18.0	2.5*	2.8

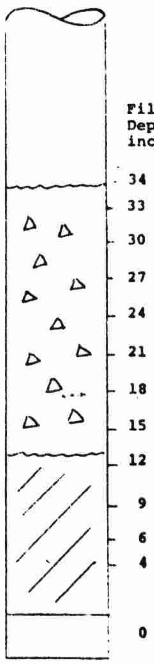
Filtration Rate - 6 Igpm/sq ft
Flocculation Velocity Gradient - 20 sec^{-1}
Alum - 15 mg/l

*Filter Breakthrough

TABLE 30

HEAD LOSS DISTRIBUTION RESULTS

Flocculation Time Study - 1972



Run #	S-26	S-28	S-24	S-25
Coal Size mm	1.05	1.05	1.05	1.05
Floc Time	8	14.5	14.5	18
Head Loss %				
	29.0	20.3	27.4	27.1
	10.0	11.2	12.5	9.9
	6.1	7.8	6.6	5.6
	4.1	4.5	4.3	3.6
	2.6	3.5	2.4	2.4
	1.9	2.6	2.3	2.7
	24.7	15.7	18.5	18.4
	15.7	17.5	18.5	19.9
	4.1	8.6	3.9	5.2
	1.2	2.6	1.9	2.8
	0.6	5.7	1.7	2.4

Filtration Rate - 6 Igpm/sq ft
Alum - 15 mg/l
Flocculation Gradient - 20 sec^{-1}

The headloss distributions are relatively constant for each of the tests. There is a slightly deeper penetration of the floc into the filter bed for test S-28 with 14.5 minutes of mixing. The headloss distributions for the other filters are given in the Appendix Supplement.

5.3.2 Flocculation Time Study 1973

Table 31 outlines tests that were run in Sarnia in 1973 using artificial turbidity to keep the raw water turbidity conditions constant between 12 and 18 FTU. Again, in a successive series of runs filter breakthrough was experienced at a lower headloss as the flocculation time was increased. The headloss distribution for the 1.05 mm coal is given in Table 32 (Appendix 22).

TABLE 31

FLOCCULATION TIME STUDY - 1973

Run Number	Filter Coal Eff. Size	Turbidity Raw	Turbidity Eff.	Floc Time	Final Head Loss	Run Time
	mm	Ftu	Ftu	min	ft	hr
56	0.9	13	0.16	4.5	8+	13.4
53	0.9	16	0.14	14.5	8+	16.0
58	0.9	15	0.16	28.0	7.0*	14.0
56	1.05	13	0.16	4.5	8+	16.8
53	1.05	16	0.15	14.5	6.0*	14.5
58	1.05	15	0.17	28.0	4.7*	11.5
56	1.55	13	0.16	4.5	8+	15.5
53	1.55	16	0.13	14.5	6.0*	13.5
58	1.55	15	0.16	28.0	4.5*	10.0

Filtration Rate - 4 Igpm/sq ft

Alum - 15 mg/l

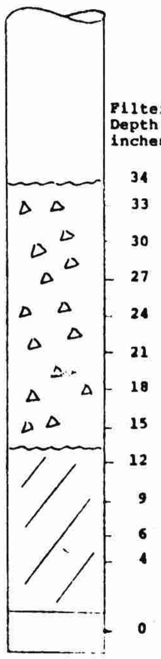
Flocculation Velocity Gradient - 20 sec^{-1}

*Filter Breakthrough

TABLE 32

HEAD LOSS DISTRIBUTION RESULTS

Flocculation Time Study - 1973



Run #	56	53	58
Coal Size mm	1.05	1.05	1.05
Floc Time	4.5	14.5	18
Head Loss %			
	20.1	17.0	25.3
	14.3	14.9	13.1
	8.0	9.4	5.6
	6.6	6.9	6.2
	4.8	5.3	3.9
	3.3	3.4	2.9
	2.1	2.1	1.4
	14.0	13.4	13.4
	20.2	11.3	18.3
	4.2	5.5	5.1
	1.2	7.6	1.5
	1.2	3.2	3.3

Filtration Rate - 4 Igpm/sq ft
Alum - 15 mg/l
Flocculation Velocity Gradient - 20 sec^{-1}

There was little difference in the headloss distribution for flocculation times of 4.5 and 18 minutes despite the wide variation in filter performance. Similar findings for the 0.9 mm and the 1.5 mm coals are listed in Appendices 22, 23 and 24.

The findings reveal that the longer the coagulated water is flocculated beyond 5 minutes, the greater the likelihood of filter breakthrough. Our hypothesis for this is that the floc formed during periods of flocculation becomes progressively weaker when the mixing time exceeds 5 minutes. During flocculation, the floc particles are subjected to constant collisions between themselves and/or mechanical devices. Each partial or complete destruction of the floc particle during one of these collisions results in a floc which on being reformed is weaker than its predecessor. Each successive action of reforming the floc particle weakens it even further. With the weaker floc, filter breakthrough takes place at a much lower headloss.

From an operational point of view, the results indicate that the probability of breakthrough can be significantly reduced by using flocculation times of 10 minutes or less.

5.4 Low Temperature Work - Toronto Lab.

Tests were carried out in the Toronto lab during the winter of 1972. Toronto tap water was cooled to below 38°F and artificial turbidity (colloidal clay) was added. The purpose was to determine if filter breakthrough could be more of a problem in low temperature waters than was found in the

warmer water field tests. The complete set of results for filter coal sizes of 1.0, 1.2, 1.3, 1.55 and 1.70 mm is given in Appendices 25 and 16.

Table 33 outlines the findings using 1.0 and 1.7 mm coal for the 1st series of tests at a filtration rate of 4 Igpm/sq ft.

TABLE 33

Low Temperature Study - Toronto Laboratory
1972

Run #	Coal e.s. mm	Alum mg/l	Polymer mg/l	Turb. Ftu	Final H.L. Ft	Filter Time hrs
T-1	1.0	10	0.115	10	8	28.5
	1.7	10	0.115	10	8	26
T-2	1.0	25	0.115	10	6	10.5
	1.7	25	0.115	10	5.5	11
T-3	1.0	10	0.115	25	8	21
	1.7	10	0.115	25	8	26
T-4	1.0	10	0	25	4.5	14
	1.7	10	0.11	25	8	20
T-5	1.0	15	0.1	50	5	14
	1.7	15	0.1	50	6	16

Filtration Rate 4 Igpm/sq ft

These results indicate the relative importance of alum, raw water turbidity and polymer dosage on filter breakthrough and filter time.

A comparison of tests T-1 and T-2 indicates that an increase in the alum by a factor of 2.5 results in a decrease in filter time (extrapolated to 8 ft headloss) by a factor of approximately 2. Raw water turbidity however (T-3 vs T-1) has a lesser effect. By increasing the turbidity by a factor of 2.5 the filter time was reduced by only an average of 14 percent. The reason that the alum dosage has a more pronounced effect on filter run than turbidity is probably because a change in alum dosage affects the floc volume to a much greater extent.

There was a need for a flocculant aid to prevent filter breakthrough in all tests. This is shown on comparing the results of the 1.0 mm e.s. coal for tests T-1 where no polymer was used and T-3 where 0.115 mg/l of Separan NP10 prevented filter breakthrough. When the raw water turbidity increased to 50 Ftu (T-5) breakthrough occurred, indicating that more polymer than that dosage shown is necessary.

Two filter runs (T-6 and T-7) were carried out at filtration rates of 2 Igpm/sq ft. These results are listed in Table 34. Breakthrough of all filters occurred in T-6. Although at the time this was unexpected, subsequent tests indicated that the 42 minute flocculation time (Appendix 26) at the low flow rate of 2 Igpm/sq ft may have played an important part, (See Section 5.3). The polymer dosage of 0.11 mg/l added in T-7 to strengthen the floc was found to be more than adequate.

TABLE 34

LOW TEMPERATURE STUDY - TORONTO LAB.
1972

Run #	Coal e.s.	Alum	Polymer	Raw	Final H.L.	Run Time
	mm	mg/l	mg/l	Ftu	ft	hrs
T-6	1.0	10	0	10	4.5	50
	1.55	10	0	10	5.5	60
T-7	1.0	13	0.11	10	8	56
	1.55	13	0.11	10	8	68
T-8	1.0*	10	0.1*	4	8	12.5
	1.55**	10	0.1	4	8	11.2

Filtration Rate - 2 Igpm/sq ft
- 6 Igpm/sq ft*
- 8 Igpm/sq ft**

Higher filtration rates (6 and 8 Igpm/sq ft) were tested in run T-8. Shorter filter runs occurred with a slightly lower gross water production per run.

Although this work was felt to be a reasonable assessment of low temperature filter performance, it nevertheless lacked the important influence of naturally occurring polymers and algae. This may have been the cause of filter breakthrough occurring at a stage within the filter cycle earlier than that experienced in field tests.

5.4.1 Low Temperature Study - Sarnia 1974

More low temperature tests ($< 38^{\circ}$ F) were carried out early in 1974 at Sarnia to confirm many of the previous findings. The observations of this study are listed in Appendices 27 and

28). As found earlier, these results indicate that flocculation velocity gradients of 300 sec^{-1} resulted in earlier breakthrough for all filters than those runs using flocculation G values of 20 sec^{-1}. The retention time study indicated, as before, that the filters were more likely to suffer breakthrough problems at a lower headloss and at an earlier time for the longer flocculation times. The best results were achieved with only 4.5 minutes of flocculation. The worst results occurred when 28 minutes of flocculation (the maximum length of time studied at Sarnia) was the pretreatment prior to filtration.

6. Declining Rate Filtration

It was felt that declining rate filtration may be superior to constant rate filtration because of the lower shear forces on the floc particles within the filter bed during the latter stages of the filter run. It was speculated that the floc deposition would take place in areas within the filter not ordinarily occupied during a constant filter-rate run. This increased rate of available storage space should lead to longer filter runs and higher water production per filter run. Indeed, Baylis [41] found that the length of filter runs may be increased by as much as 50 per cent.

It was also hypothesized that the lower shear forces on all particles deposited in the filter bed should reduce the chance of breakthrough and produce a better quality of water. Hudson [42] found that by removing the rate controller on a filter in Wyandotte, Mich. the water produced from this filter was of a better quality than that produced during constant rate controlled filtration.

The results of our direct filtration declining rate studies are listed in Table 35. In all cases the total water produced by the declining rate filter exceeded its production at a constant rate of filtration. The percentage increase ranged from 5 to 25. The effluent quality and headloss distributions (Appendix 29) were similar in every test except with the 2.0 mm e.s. coal where there was a deeper penetration of the floc in the declining filtration rate test.

More work would have to be done to conclude any definite advantages or disadvantages of declining rate filtration.

TABLE 35

DECLINING RATE vs CONSTANT RATE FILTRATION

Run Number	Filter Coal Eff Size	Filtration Rate Initial	Final	Average	Run Time	Production to 8 ft Head Loss
	mm	Igpm/sq ft			hrs	Ig/sq ft
H-13	1.0	4.0	1.6	2.55	23	3500
H-12	1.0	2.6	2.6	2.6	18	2800
H-13	2.0	4.0	1.9	2.9	25	4350
H-11	2.0	2.6	2.6	2.6	25	3900
S-6	1.0	6.0	2.2	4.25	31.5	8350*
S-5	1.0	4.0	4.0	4.0	33.0	7900
S-7	1.55	10.0	4.0	7.4	10.5	4850**
S-8	1.55	7.4	7.4	7.4	9.0	4000

* projected from 7.5 ft Headloss

** projected from 7.0 ft Headloss

7 DISCUSSION

Direct filtration is a viable alternative to conventional systems using sedimentation facilities when the raw water turbidity,,colour and algae levels, are as follows:

Turbidity

The turbidity levels should be low enough to allow alum dosages of less than 12 mg/l to be used on a continuous basis. Under these conditions, the length of filter run at a filtration rate of 4 Igpm/sq ft would be in the range of 16-20 hrs. This length of filter run is felt to be sufficiently long to ensure a waste volume of less than 4% of the product.

Sporadic periods of high turbidity not requiring more than 20 mg/l of alum could be tolerated on a short term basis. Polymer facilities are a necessity under these conditions to prevent filter breakthrough.

If the high turbidity levels persist, the short filter runs may tax the backwash water facilities beyond the design limits. If this periodic multi-day high turbidity condition occurs often, the use of air scour to minimize the backwash water requirements becomes an essential design consideration in direct filtration plants.

Colour

Highly coloured waters in Ontario require coagulant dosages greater than those needed for Great Lakes waters which have colour levels usually below 5 Hazen. Even the lower colour levels of 25 - 30 Hazen usually require 20^{+} mg/l of

alum. This coagulant level would lead to short filter runs and would necessitate the continuous use of polymer to prevent filter breakthrough. The use of polymers as primary coagulants to reduce or replace alum may allow the direct filtration process to be used in localities where the colour level is as high as 25 Hazen. Waters higher in colour would need a substantial colour reduction through oxidation or absorption mechanisms if coagulant dosages were to be kept low enough to allow the direct filtration process to be used.

<u>Algae</u>

Diatom levels between 1000 and 2500 Asu/ml will require the use of coarse coal to extend the length of the filter runs. However, the coarse coal will require more frequent use of a filter aid polymer than the finer coal sizes. In addition, a backwash rate of 20 Igpm/sq ft will be required to ensure a good filter backwash.

<u>Coal Size</u>

If the diatom levels are less than 1000 Asu/ml and the colour is less than 5 Hazen, the optimum filter coal effective size is near 1.1 mm. This coal size should be able to handle turbidity levels of 100^+ Ftu on a short term basis at filtration rates up to 4 Igpm/sq ft. Naturally, the use of a polymer filter aid will be required to prevent breakthrough. If the high turbidity levels persist, the short filter runs may decrease the product/backwash water ratio below design limits.

Waste Water

With the direct filtration process using considerably lower dosages of alum than conventional systems of similar raw water quality, the total weight of the waste water solids will be proportionally reduced. This amount of solids may be of importance in view of the existing limitations on waste water disposal. With the possibility of the eventual disposal of wastes through a thickening followed by filtration system,or by means of sewerage, the solids content of the wastes becomes an important economical consideration.

Plant Operation

The direct filtration process requires an operator who is fully conversant with all aspects of the coagulation, flocculation and filtration processes.

Small, one or two man, plant operations would be more suited to the conventional complete treatment processes (with the built in buffer to adverse conditions) unless the filtration process was carefully monitored automatically with reliable instruments.

Because of continuous development in the water treatment process field such as polymers being used as coagulant or filtration aids, the plant operation should be geared toward the continual upgrading of the plant facilities as the technology develops. This would require the design of full scale plant flexibility to enable developmental research to be carried out.

8 CONCLUSIONS

Many of the conclusions outlined here are supported by other researchers who have carried out similar tests on sedimentation followed by filtration systems. Other conclusions were found to be specific to this study on direct filtration.

COAGULANTS

(1) The length of filter runs was shown to vary inversely with the suspended solids loadings excluding algae. Of the remaining suspended solids, the alum played the dominant role in determining the overall length of filter run.

(2) Either alum or ferric chloride, used as primary coagulants, produced similar effluent quality.

(3) Cationic polyelectrolytes can reduce alum requirements without a reduction in effluent quality.

(4) The probability of filter breakthrough prior to terminal headloss increased with higher coagulant dosages.

FILTER MEDIA

(1) In the absence of diatoms, the best effective size coal with regard to effluent quality, length of filter runs and floc distribution within the filter bed was near 1.05 mm.

(2) In dual media filters, the effluent turbidity was not a function of the effective size of the coal within the size range of 0.9 to 1.55 mm.

(3) There was little change in the effluent turbidity for the filtration rates of 2 through 6 Igpm/sq ft.

(4) The optimum headloss distribution for maximizing filter runs was approximately 75 percent for the coal and 25 percent for the sand.

DIATOMS

(1) Diatom levels as low as 200 Asu/ml altered the headloss distribution within the filter bed.

(2) Diatom counts of more than 1000 Asu/ml had a marked influence on the length of filter runs, particularly with coals of effective size less than 1.0 mm.

(3) Filter coal with an effective size of 1.5 mm operated successfully with diatom levels averaging 2500 Asu/ml to produce filter runs in excess of 12 hours at 4 Igpm/sq ft.

(4) Diatom levels above 5000 Asu/ml for prolonged periods of time would best be taken care of by other means such as sedimentation or microstraining facilities.

BREAKTHROUGH

The following factors increased the probability of filter breakthrough in direct filtration.

(a) increasing the effective size of the coal or sand

(b) increasing the alum dosage

(c) increasing the filtration rate

(d) increasing the flocculation gradient above 20 sec^{-1}

(e) increasing the flocculation time to more than 10 minutes

(f) decreasing the depth of media

PREVENTION OF BREAKTHROUGH

(1) Polymers, particularly non-ionic filter aids, prevented breakthrough on all media sizes up to 1.55 mm under all conditions encountered.

(2) The optimal use of polymer would best be determined with the use of interface turbidity control devices.

(3) The optimum dosage point of the polymer was the filter inlet.

(4) The polymer demand for the prevention of filter breakthrough increased as the filter media size increased.

pH AND ALUM

(1) An increase in the flocculated water pH to levels above 7.45 led to a filtered water residual aluminum value in excess of 0.1 mg/l.

(2) An increase in the pH resulting in a filtered water level above a pH of 8 led to a deterioration in effluent quality and a marked increase in the length of filter run.

9 FUTURE WORK

If the direct filtration process is to be an alternative to conventional facilities as the design filtration rates are increased above 4 Igpm/sq ft, ways and means of increasing the length of filter runs lie in the reduction of floc volume. Research should be directed to the reduction of floc volume through the use of mixing at high flocculation gradients plus a floc strengthening aid or with the use of a polymer as a primary coagulant to replace all or part of the conventional metal salt demand. If any or all of these techniques can result in longer filter runs, the future of direct filtration, particularly on the Great Lakes, looks promising.

APPENDIX A

DIRECT FILTRATION DESIGN DATA

Location	Plant Capacity	Mixing Data Retention Time Flash Mix	Flocculation	Turbidity Raw Avg.	Treated Avg.
	MIGPD	min	min	Ftu	Ftu
Lake Huron WTP	36.0	2.1	45	7	0.4
Port Elgin WTP	1.1	- 6.5	-	10	0.5
Owen Sound WTP	2.0	1.0	78	4	1.0

FILTRATION DATA

Location	Maximum Filtration Rate	Filter Media: Coal Depth	Coal e.s.	Coal u.c.	Sand Depth	Sand e.s.	Sand u.c.
	Igpm/sq ft	in.	mm		in.	mm	
Lake Huron WTP	2.0	18	0.92	1.7	12	0.5	1.8
Port Elgin WTP	2.5	-	-	-	24	0.5	1.8
Owen Sound WTP	1.7	18	0.92	1.7	12	0.5	1.8

RAW WATER QUALITY

Location	pH	Hardness ppm $CaCO_3$	Alkalinity ppm $CaCO_3$	Iron ppm Fe	Colour Hazen	Chloride ppm Fe
Lake Huron WTP	7.5-8.3	90-100	75-85	0.05	<5	5
Port Elgin WTP	7.5-8.3	90-100	75-85	0.05	<5	5
Owen Sound WTP	7.5-8.3	100-105	80-86	0.05	<5	6

APPENDIX 1

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Oct 16	S-22	54	12	0.45	20	0.9	4	15	0	20*	0.18	20	14.5	6	6	11.5	2,750	74	26
			13	0.45	21	1.0	4	15	0	20	0.18	20	14.5	4.5	4.5	11.5	2,750	54	46
			12	0.45	20	1.55	4	15	0	20	0.20	20	14.5	3	3	7.2	1,750	42	58
Oct 13	S-21	54	12	0.45	20	0.9	4	20	0	53*	-	20	14.5	3.5	3.5	2.3	550	71	29
			13	0.45	21	1.0	4	20	0	53	-	20	14.5	3	3	2	500	39	61
			12	0.45	20	1.55	4	20	0	53	-	20	14.5	2.5	2.5	1.5	350	38	62
Jan 28	61	33	13	0.45	22	0.9	4	12	0	14**	0.23	20	14.5	5.8	5.8	15.0	3,600	71	29
			13	0.45	22	1.05	4	12	0	14	0.20	20	14.5	4.3	4.3	13.5	3,250	57	43
			13	0.45	22	1.55	4	12	0	14	0.23	20	14.5	4.3	4.3	11.8	2,850	54	46
July 4	18	53	13	0.45	22	0.9	4	15	0	20**	0.14	20	14.5	7.5	7.5	9.5	2,300	87	13
			13	0.45	22	1.05	4	15	0	20	0.20	20	14.5	4.0	4.0	8.5	2,050	67	33
			13	0.45	22	1.55	4	15	0	20	0.20	20	14.5	2.5	2.5	4.5	1,100	54	46

* Natural Turbidity
** Turbidity added to raw water

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APPENDIX 1

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APPENDIX 2

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media Sand Depth in.	Filter Media Sand Eff mm	Filter Media Coal Depth in.	Filter Media Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals Alum ppm	Chemicals Poly ppm	Turbidity Raw FTU *	Turbidity Eff. FTU	Flocculation G Sec^{-1}	Flocculation Time min.	Head Loss Ft. Final	Head Loss Ft. Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution Coal %	Head Loss Distribution Sand %
July 12	22	66	13	0.45	22	0.9	4	12	0	40	0.35	20	18	2.6	2.6	5	1,200	74	26
			13	0.45	22	1.05	4	12	0	40	0.35	20	18	2.3	2.3	6	1,450	56	44
			13	0.45	22	1.55	4	12	0	40	1.5	20	18	1.8	1.8	3	700	33	67
July 10	20	57	13	0.45	22	0.9	4	17	0	40	0.25	20	18	5.8	5.8	9.5	2,300	85	15
			13	0.45	22	1.05	4	17	0	40	0.25	20	18	3.7	3.7	7.5	1,800	63	37
			13	0.45	22	1.55	4	17	0	40	0.25	20	18	2.8	2.8	5.5	1,300	52	48
July 11	21	63	13	0.45	22	0.9	4	28	0	40	0.18	20	18	1.8	1.8	2.5	600	74	36
			13	0.45	22	1.05	4	28	0	40	0.20	20	18	2.0	2.0	2.8	650	51	49
			13	0.45	22	1.55	4	28	0	40	0.18	20	18	1.8	1.8	2.5	600	34	66
July 18	25	65	13	0.45	22	0.9	4	20	0	80+	0.25	20	18	2.5	2.5	4.5	1,100	81	19
			13	0.45	22	1.05	4	20	0	80+	0.25	20	18	2.0	2.0	3.3	800	62	38
			13	0.45	22	1.55	4	20	0	80+	0.25	20	18	1.8	1.8	2.8	650	36	64

* Turbidity added to raw water

APPENDIX 2

APPENDIX 3

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals Alum ppm	Chemicals Poly ppm	Turbidity Raw FTU *	Turbidity Eff. FTU	Flocculation G Sec^{-1}	Flocculation Time min.	Head Loss Ft. Final	Head Loss Ft. Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution Coal %	Head Loss Distribution Sand %
Oct 25	52	56	13	0.45	22	0.9	4	13.6	0	13	0.14	20	14.5	8	-	15.4	3,700	77	23
			13	0.45	22	1.05	4	13.6	0	13	0.14	20	14.5	7	7	16.0	3,850	56	44
			13	0.45	22	1.55	4	13.6	0	13	0.14	20	14.5	7	7	13.5	3,250	51	49
Oct 29	53	55	13	0.45	22	0.9	4	12	0	16	0.14	20	14.5	8	-	16.0	3,850	78	22
			13	0.45	22	1.05	4	12	0	16	0.15	20	14.5	6	6	14.5	3,500	59	41
			13	0.45	22	1.55	4	12	0	16	0.13	20	14.5	6	6	13.5	3,250	49	51

* Turbidity added to raw water.

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APPENDIX 4 DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Oct 18	S-26	48	12	0.45	20	0.9	6	15	0	7	0.18	20	8	8	-	8.7	3,100	78	22
			13	0.45	21	1.0	6	15	0	7	0.18	20	8	8	-	10.0	3,600	54	46
			12	0.45	20	1.55	6	15	0	7	0.18	20	8	8	-	9.5	3,400	33	67
Oct 17	S-25	54	12	0.45	20	0.9	6	15	0	18	0.19	20	18	4.2	4.2	4.5	1,600	69	31
			13	0.45	21	1.0	6	15	0	18	0.19	20	18	3.6	3.6	4.2	1,500	51	49
			12	0.45	20	1.55	6	15	0	18	0.23	20	18	2.5	2.5	2.8	1,000	40	60
Oct 17	S-24	54	12	0.45	20	0.9	6	15	0	19	0.20	20	14.5	5.6	5.6	5.8	2,100	77	23
			13	0.45	21	1.0	6	15	0	19	0.21	20	14.5	4	4	5.2	1,850	55	45
			12	0.45	20	1.55	6	15	0	19	0.25	20	14.5	3	3	3.6	1,300	33	67
Oct 12	S-20	54	12	0.45	20	0.9	6	20	0	45	0.30	20	14.5	3.5	3.5	2.5	900	76	24
			13	0.45	21	1.0	6	20	0	45	0.30	20	14.5	3	3	2.5	900	52	48
			12	0.45	20	1.55	6	20	0	45	0.30	20	14.5	2.8	2.8	2.0	700	37	63

* Natural

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APPENDIX 5

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Filter Media: Sand Eff. mm	Filter Media: Coal Depth in.	Filter Media: Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Chemicals: Poly ppm *	Turbidity: Raw FTU **	Turbidity: Eff. FTU	Flocculation: G Sec^{-1}	Flocculation: Time min.	Head Loss Ft.: Final	Head Loss Ft.: Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Head Loss Distribution: Sand %
17 July	24	65	13	0.45	22	0.9	4	17	0.1	40	0.17	20	18	8	-	13.0	3,100	77	29
			13	0.45	22	1.05	4	17	0.1	40	0.18	20	18	6.5	6.5	12.0	2,900	57	43
			13	0.45	22	1.55	4	17	0.6	40	0.25	20	18	8	-	9.2	2,200	92	8
23 July	27	68	13	0.45	22	0.9	4	20	0.20	80+	0.20	20	18	8	-	11	2,650	95	5
			13	0.45	22	1.05	4	20	0.25	80+	0.25	20	18	8	-	11	2,650	77	23
			13	0.45	22	1.55	4	20	0.45	80+	0.25	20	18	8	-	9	2,150	95	5
Aug 9	33	65	13	0.45	22	0.9	4	20	0.4	175	0.28	20	18	8	-	7.5	1,800	97	3
			13	0.45	22	1.05	4	20	0.4	175	0.35	20	18	8	-	9.8	2,350	94	6
			13	0.45	22	1.55	4	20	0.4	175	0.31	20	18	8	-	12.5	3,000	71	29

* Separan NP10
** Turbidity added to raw water

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Date	Run #	Temp °F	Filter Media: Sand Depth in.	Filter Media: Sand Eff. mm	Filter Media: Coal Depth in.	Filter Media: Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Chemicals: Poly ppm *	Turbidity: Raw FTU **	Turbidity: Eff. FTU	Flocculation: G Sec^{-1}	Flocculation: Time min.	Head Loss Ft.: Final	Head Loss Ft.: Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Head Loss Distribution: Sand %
Oct 24	S-29	50	12	0.45	20	0.9	6	10	0.10	35	0.25	20	14.5	8	8	8.1	2,900	75	25
			13	0.45	21	1.0	6	10	0.10	35	0.25	20	14.5	6.5	6.5	8.2	2,950	50	50
			12	0.45	20	1.55	6	10	0.10	32	0.32	20	14.5	4.5	4.5	5.6	2,000	37	63
Oct 24	S-30	50	12	0.45	20	0.9	6	10	0.20	44	0.35	20	14.5	8	-	5.5	2,000	83	17
			13	0.45	21	1.0	6	10	0.20	44	0.35	20	14.5	8	-	7.3	2,650	55	45
			12	0.45	20	1.55	6	10	0.20	44	0.60	20	14.5	5.5	5.5	5.0	1,800	34	66
Oct 25	S-31	50	12	0.45	20	0.9	4	10	0.10	26	0.19	20	14.5	8	-	13.2	3,150	78	22
			13	0.45	21	1.0	4	10	0.10	26	0.20	20	14.5	8	-	16.2	3,900	54	46
			12	0.45	20	1.55	4	10	0.10	28	0.25	20	14.5	5	5	10	2,400	49	51

* Separan NP10
** Natural Turbidity

APPENDIX 6

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APPENDIX 7

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Filter Media: Sand Eff mm	Filter Media: Coal Depth in.	Filter Media: Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Chemicals: Poly ppm	Turbidity: Raw FTU x	Turbidity: Eff. FTU	Flocculation: G Sec^{-1}	Flocculation: Time min.	Head Loss Ft.: Final	Head Loss Ft.: Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Head Loss Distribution: Sand %
Feb 6	67	33	13	0.45	22	0.9	4	18	0.11*	32	0.23	20	28	7.0	7.0	9.3	2,250	76	24
			13	0.45	22	1.05	4	19	0.11*	32	0.23	20	28	7.0	7.0	8.8	2,100	55	45
			13	0.45	22	1.55	4	19	0.11*	32	0.23	20	28	5.4	5.4	7.5	1,800	44	56
Feb 7	68	33	13	0.45	22	0.9	4	18	0.105**	30	0.19	20	28	8	-	3.0	700	96	4
			13	0.45	22	1.05	4	18	0.105**	31	0.21	20	28	8	-	4.4	1,050	94	6
			13	0.45	22	1.55	4	18	0.105**	30	0.19	20	28	8	-	5.7	1,350	95	5
Feb 8	69	33	13	0.45	22	0.9	4	18	0.10***	31	0.16	20	28	8	-	10.2	2,450	68	32
			13	0.45	22	1.05	4	18	0.10***	31	0.18	20	28	5.6	5.6	10.0	2,400	53	47
			13	0.45	22	1.55	4	18	0.10***	31	0.16	20	28	6.1	6.1	10.0	2,400	43	57

* Separan NP10

** Purifloc N20

*** Nalcolyte 8171

x artificialturbidity added to raw

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Ontario

APPENDIX 8

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Filter Media: Sand Eff. mm	Filter Media: Coal Depth in.	Filter Media: Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Chemicals: Poly ppm	Turbidity: Raw FTU *	Turbidity: Eff. FTU	Flocculation: G Sec^{-1}	Flocculation: Time min.	Head Loss Ft.: Final	Head Loss Ft.: Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Head Loss Distribution: Sand %
July 31	30	68	13	0.45	22	0.9	6	6	0	1.5	0.3	20	14.5	8	-	16.5	5,950	78	22
			13	0.45	22	1.05	6	6	0	1.5	0.3	20	14.5	8	-	16	5,750	48	52
			13	0.45	22	1.55	6	6	0	1.5	0.3	20	14.5	8	-	22	1,900	27	73
							pH = 7.0												
July 30	29	67	13	0.45	22	0.9	6	6	0	1.5	0.23	20	14.5	8	-	22	7,900	78	22
			13	0.45	22	1.05	6	6	0	1.5	0.25	20	14.5	8	-	27	9,700	48	52
			13	0.45	22	1.55	6	6	0	1.5	0.25	20	14.5	8	-	31	11,150	30	70
							pH = 7.85												

* Natural

APPENDIX 8

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APPENDIX 9

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
27 Sept	S-12	63	12	0.45	20	0.9	4	3.8	0	2.3	0.25	20	14.5	8	-	39	9,350	88	12
			12	0.45	21.5	1.0	4	3.8	0	2.3	0.25	20	14.5	3.7	-	48	11,500	61	39
			12	0.45	20	1.5	4	3.8	0	2.3	0.25	20	14.5	3.2	-	48	11,500	38	62
25 Sept	S-11	63	12	0.45	20	0.9	4	6.5	0	0.7	0.16	20	14.5	8	-	28	6,700	92	8
			12	0.45	21.5	1.0	4	6.5	0	0.7	0.16	20	14.5	8	-	38	9,100	67	33
			12	0.45	20	1.5	4	6.5	0	0.7	0.16	20	14.5	8	-	34.5	8,300	68	32
13 June	S-2	50	12	0.45	25	1.0	4	10	0	3.5	0.15	20	14.5	8	-	16.2	3,900	87	13
			12	0.45	20	1.3	4	10	0	3.5	0.15	20	14.5	6	6	17.5	4,200	57	43
			12	0.45	20	1.55	4	10	0	3.5	0.15	20	14.5	5	5	17	4,100	53	47
Oct 16	S-22	54	12	0.45	20	0.9	4	15	0	20	0.18	20	14.5	6	6	11.5	2,750	74	26
			12	0.45	21	1.0	4	15	0	20	0.18	20	14.5	4.5	4.5	11.5	2,750	54	46
			12	0.45	20	1.55	4	15	0	20	0.20	20	14.5	3	3	7.2	1,750	42	58
Aug 21	S-9	66	12	0.45	20	0.9	4	40	0	0.8	0.10	20	14.5	7	7	8	1,900	82	18
			12	0.45	22	1.0	4	40	0	0.8	0.10	20	14.5	5	5	7.7	1,850	52	48
			12	0.45	20	1.5	4	40	0.35	0.8	0.10	20	14.5	7	7	8	1,900	48	52

* Natural

APPENDIX 9

APPENDIX 10

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Oct 30	S-32	47	12	0.45	20	0.9	6	4	0	1.5	0.18	20	14.5	8	-	18	6,500	77	23
			13	0.45	21	1.0	6	4	0	1.5	0.18	20	14.5	8	-	27	9,700	46	54
			12	0.45	20	1.55	6	4	0	1.5	0.25	20	14.5	8	-	28	10,050	28	72
Oct 19	S-27	48	12	0.45	20	0.9	6	10	0	4.5	0.25	20	14.5	8	-	12.2	4,400	78	22
			13	0.45	21	1.0	6	10	0	4.5	0.25	20	14.5	6.7	6.7	12.2	4,400	55	45
			12	0.45	20	1.55	6	10	0	4.5	0.25	20	14.5	4.5	4.5	8	2,400	40	60
Oct 11	S-19	57	12	0.45	20	0.9	6	10	0	8	0.16	50	14	8	-	11.5	4,150	77	23
			13	0.45	21	1.0	6	10	0	8	0.15	50	14	7.5	7.5	12	4,300	49	51
			12	0.45	20	1.55	6	10	0	8	0.18	50	14	5.5	5.5	9	3,250	40	60
Oct 20	S-28	48	12	0.45	20	0.9	6	15	0	4.5	0.15	20	14.5	8	8	8.8	3,200	76	24
			13	0.45	21	1.0	6	15	0	4.5	0.15	20	14.5	5.5	5.5	6.2	2,250	49	51
			12	0.45	20	1.55	6	15	0	4.5	0.20	20	14.5	4.8	4.8	6.0	2,150	38	62

* Natural

APPENDIX 10

APPENDIX 11

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media				Filtration Rate	Chemicals		Turbidity		Flocculation		Head Loss Ft.		Run Length	Total Filtered	Head Loss Distribution	
			Sand		Coal			Alum	Poly	Raw	Eff.			Final	Break Through			Coal	Sand
			Depth in.	Eff. mm	Depth in.	Eff mm	IGPM/ft^2	ppm	ppm	FTU *	FTU	G Sec^{-1}	Time min.			Hours	Imp. Gal/ft^2	%	%
May 28	4	48	13	0.45	22	0.9	4	6	0	0.85	0.20	20	14.5	8	-	25.5	6,100	86	14
			13	0.45	22	1.05	4	6	0	0.85	0.19	20	14.5	8	-	37.5	9,000	55	45
			13	0.45	22	1.55	4	6	0	0.85	0.24	20	14.5	8	-	45.5	11,000	30	70
July 16	24	65	13	0.45	22	0.9	4	6	0	0.9	0.22	20	14.5	8	-	40	9,600	71	29
			13	0.45	22	1.05	4	6	0	0.9	0.21	20	14.5	8	-	43	10,500	40	60
			13	0.45	22	1.55	4	6	0	0.9	0.27	20	14.5	8	-	50	12,000	26	74

* Natural

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APPENDIX 12

DIRECT FILTRATION

Date 1973	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Oct24-5	51	57	13	0.45	22	0.9	4	1.75	0	1.0*	0.16	20	14.5	8	-	20	4,800	86	14
			13	0.45	22	1.05	4	1.75	0	1.0	0.13	20	14.5	8	-	28.8	6,900	62	38
			13	0.45	22	1.55	4	1.75	0	1.0	0.13	20	14.5	8	-	28	6,700	53	47
Oct 23	49	57	13	0.45	22	0.9	4	4.0	0	6.5*	0.18	20	14.5	8	-	12.8	3,100	94	6
			13	0.45	22	1.05	4	4.0	0	6.5	0.18	20	14.5	8	-	18	4,300	74	26
			13	0.45	22	1.55	4	3.7	0	6.5	0.16	20	14.5	8	-	17	4,100	70	30
Oct 22	48	57	13	0.45	22	0.9	4	4.3	0	3 *	0.14	20	14.5	8	-	13	3,100	90	10
			13	0.45	22	1.05	4	4.3	0	3	0.14	20	14.5	8	-	16.5	4,000	76	24
			13	0.45	22	1.55	4	4.3	0	3	0.16	20	14.5	8	-	14.5	3,500	69	31
Oct 24	50	57	13	0.45	22	0.9	4	6.7	0	17**	0.18	20	14.5	8	-	9.5	2,300	97	3
			13	0.45	22	1.05	4	6.7	0	17	0.22	20	14.5	8	-	12.5	3,000	81	19
			13	0.45	22	1.55	4	6.7	0	17	0.16	20	14.5	8	-	11.8	2,800	67	33

* Natural Turbidity
** Turbidity added to raw water

APPENDIX 12

MOE 08-114 6-74

APPENDIX 13

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
July 4	19	53	13	0.45	22	0.9	4	0	0.2	1.3	0.43	20	14.5	6.1	-	50	12,000	97	3
			13	0.45	22	1.05	4	0	0.2	1.3	0.5	20	14.5	3	-	50	12,000	84	16
			13	0.45	22	1.55	4	0	0.2	1.3	0.5	20	14.5	2.1	-	50	12,000	67	33
July19	26	65	13	0.45	22	0.9	4	0	0.4	1.7	0.8	20	14.5	2.0	-	23.5	5,650	91	9
			13	0.45	22	1.05	4	0	0.4	1.7	0.9	20	14.5	1.5	-	23.5	5,650	58	42
			13	0.45	22	1.55	4	0	0.4	1.7	0.9	20	14.5	1.4	-	23.5	5,650	44	56'
July24	28	68	13	0.45	22	0.9	4	0	0.4	1.8	0.6	20	18	1.3	-	73	17,500	91	9
			13	0.45	22	1.05	4	0	0.4	1.8	0.6	20	18	1.2	-	73	17,500	75	25
			13	0.45	22	1.55	4	0	0.4	1.8	0.65	20	18	0.8	-	73	17,500	61	39
Aug 29	42	70	13	0.45	22	0.9	4	0	0.2-0.4	0.8	0.45	550	11	2.6	-	43.5	10,450	93	7
			13	0.45	22	1.05	4	0	0.2-0.4	0.8	0.45	550	11	1.6	-	43.5	10,450	82	18
Sept. 3	43	70	13	0.45	22	0.9	4	0	0.3**	1.1	0.48	20	18	2.3	-	21	5,050	91	9
			13	0.45	22	1.05	4	0	0.3**	1.1	0.45	20	18	1.5	-	21	5,050	84	16
			13	0.45	22	1.55	4	0	0.3**	1.1	0.50	20	18	1.5	-	21	5,050	74	26

* Natural

** Nalcolyte 8101

APPENDIX 13

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Aug 18	37	67	13	0.45	22	0.9	6	6	0	1.5*	0.18	20	14.5	8	-	23.5	8,450	81	19
			13	0.45	22	1.05	6	6	0	1.5	0.20	20	14.5	8	-	27	9,700	54	46
			13	0.45	22	1.55	6	6	0	1.5	0.20	20	14.5	8	-	29	10,450	40	60
Aug 14	35	67	13	0.45	22	0.9	6	5.5	0	1.5*	0.16	20	14.5	8	-	24	8,650	83	17
			13	0.45	22	1.05	6	5.5	0	1.5	0.20	20	14.5	8	-	29	10,450	56	44
			13	0.45	22	1.55	6	5.5	0	1.5	0.16	20	14.5	8	-	31	11,150	39	61
Aug 20	38	71	13	0.45	22	0.9	4	10	0	12**	0.12	20	18	8	-	19	6,850	93	7
			13	0.45	22	1.05	4	10	0	12	0.17	20	18	8	-	23	8,300	62	38
			13	0.45	22	1.55	4	10	0	12	0.12	20	18	8		23.5	8,450	43	57
Aug 21	39	71	13	0.45	22	0.9	4	10	0	12**	0.23	20	18	8	-	19	6,850	90	10
			13	0.45	22	1.05	4	10	0	12	0.23	20	18	8	-	25	9,000	69	31
			13	0.45	22	1.55	4	10	0	12	0.23	20	18	8	-	24.5	8,800	40	60

* natural
** turbidity added to raw water

MOE 08-114 6-74

APPENDIX 15

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals Alum ppm	Poly ppm	Turbidity Raw FTU *	Eff. FTU	Flocculation G Sec^{-1}	Time min.	Head Loss Ft. Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution Coal %	Sand %
Oct 2	S-13	60	12	0.45	20	0.9	6	10	0	0.8	0.17	20	14.5	8	-	9	3250	91	9
			13	0.45	21	1.05	6	10	0	0.8	0.18	20	14.5	8	-	13	4700	72	28
			12	0.45	20	1.55	6	10	0	0.8	0.18	20	14.5	8	-	13	4700	42	58
Oct 5	S-16	60	12	0.45	20	0.9	6	10	0	0.7	0.10	50	14	8	-	10.5	3800	84	16
			13	0.45	21	1.05	6	10	0	0.7	0.10	50	14	8	-	13	4700	52	48
			12	0.45	20	1.55	6	10	0	0.7	0.10	50	14	8	-	12.5	4500	33	67
~~Oct 3~~	~~S-14~~	~~60~~	~~12~~	~~0.45~~	~~20~~	~~0.9~~	~~6~~	~~15~~	~~0~~	~~0.8~~	~~0.10~~	~~20~~	~~14.5~~	~~8~~	~~-~~	~~7~~	~~2500~~	~~93~~	~~7~~
			13	0.45	21	1.05	6	15	0	0.8	0.11	20	14.5	8	-	9.7	3500	62	38
			12	0.45	20	1.55	6	15	0	0.8	0.13	20	14.5	8	-	9	3250	42	58
Oct 10	S-18	57	12	0.45	20	0.9	6	15	0	1.5	0.10	50	14.5	8	-	7	2500	85	15
			13	0.45	21	1.05	6	15	0	1.5	0.10	50	14.5	8	-	9	3250	54	46
			12	0.45	20	1.55	6	15	0	1.5	0.10	50	14.5	7	7	8	2900	34	66

*Natural

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APPENDIX 16 — DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Oct 29	53	55	13	0.45	22	0.9	4	12	0	16	0.14	20	14.5	8	-	16.0	3850	78	22
			13	0.45	22	1.05	4	12	0	16	0.15	20	14.5	6	6	14.5	3500	59	41
			13	0.45	22	1.55	4	12	0	16	0.13	20	14.5	6	6	13.5	3250	34	66
Oct 30	54	55	13	0.45	22	0.9	4	12	0	12.5	0.14	100	14.5	8	-	15	3600	82	18
			13	0.45	22	1.05	4	12	0	12.5	0.13	100	14.5	6	6	16.5	3950	65	35
			13	0.45	22	1.55	4	12	0	12.5	0.15	100	14.5	6	6	13.5	3250	32	68
Oct 31	55	55	13	0.45	22	0.9	4	12	0	14	0.14	300	14.5	7.3	7.3	17.0	4100	78	22
			13	0.45	22	1.05	4	12	0	14	0.15	300	14.5	4.5	4.5	13	3100	56	44
			13	0.45	22	1.55	4	12	0	14	0.15	300	14.5	4.5	4.5	11.5	2750	29	71

* Turbidity added to raw

APPENDIX 16

MOE 08-114 6-74

APPENDIX 17

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Nov 2	56	55	13	0.45	22	0.9	4	12	0	13	0.16	20	4.5	8	-	13.4	3200	90	10
			13	0.45	22	1.05	4	12	0	13	0.16	20	4.5	8	-	16.8	4050	59	41
			13	0.45	22	1.55	4	12	0	13	0.16	20	4.5	8	-	15.5	3700	35	65
Nov 3	57	55	13	0.45	22	0.9	4	12	0	14	0.16	300	4.5	8	-	13.0	3100	86	14
			13	0.45	22	1.05	4	12	0	14	0.16	300	4.5	7.5	7.5	17.3	4150	62	38
			13	0.45	22	1.55	4	12	0	14	0.16	300	4.5	7.2	7.2	15.5	3700	32	68
Nov 5	58	53	13	0.45	22	0.9	4	12	0	15	0.16	20	28	7	7	14.0	3350	81	19
			13	0.45	22	1.05	4	12	0	15	0.17	20	28	4.7	4.7	11.5	2750	58	42
			13	0.45	22	1.55	4	12	0	15	0.16	20	28	4.5	4.5	10.0	2400	29	71
Nov 7	60	50	13	0.45	22	0.9	4	12	0	15	0.14	300	28	6	6	13.0	3100	79	21
			13	0.45	22	1.05	4	12	0	15	0.14	300	28	3.6	3.6	12.0	2900	56	44
			13	0.45	22	1.55	4	12	0	15	0.14	300	28	3.7	3.7	9.5	2300	70	30

* Turbidity added to raw

MOE 08-114 6-74

Ministry of the Environment

Ontario

APPENDIX 18

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Nov 28	61	33	13	0.45	22	0.9	4	12	0	14	0.23	20	14.5	5.8	5.8	15.0	3600	71	29
			13	0.45	22	1.05	4	12	0	14	0.20	20	14.5	4.3	4.3	13.5	3250	57	43
			13	0.45	22	1.55	4	12	0	14	0.23	20	14.5	4.3	4.3	11.8	2850	37	63
Nov 29	62	33	13	0.45	22	0.9	4	12	0	14	0.22	300	14.5	6.0	6.0	10.8	2600	79	21
			13	0.45	22	1.05	4	12	0	14	0.22	300	14.5	4.3	4.3	9.0	2150	54	46
			13	0.45	22	1.55	4	12	0	14	0.23	300	14.5	4.3	4.3	7.5	1800	38	62

* Trubidity added to raw

MOE 08-114 6-74

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DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Oct 4	S-15	60	12	0.45	20	0.9	6	20	0	0.8	0.10	20	14.5	8	-	7	2500	82	18
			13	0.45	21	1.05	6	20	0	0.8	0.10	20	14.5	8	-	8	2900	56	44
			12	0.45	20	1.55	6	20	0	0.8	0.10	20	14.5	7	7	7	2500	38	62
Oct 6	S-17	60	12	0.45	20	0.9	6	20	0	0.8	0.10	50	14	8	-	7	2500	78	22
			13	0.45	21	1.05	6	20	0	0.80	0.10	50	14	8	-	6.5	2350	50	50
			12	0.45	20	1.55	6	20	0	0.8	0.10	50	14	5.5	5.5	6	2150	32	68

* Natural

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APPENDIX 20

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
June 20	14	50	13	0.45	22	0.9	4	6.2	0	1.5	0.16	20	14.5	8	-	21	5050	89	11
			13	0.45	22	1.05	4	6.2	0	1.5	0.17	20	14.5	8	-	39.0	9350	55	45
			13	0.45	22	1.55	4	6.2	0	1.5	0.20	20	14.5	8	5	40	9600	27	73
June 25	16	55	13	0.45	22	0.9	4	6	0	1.2	0.16	50	14.5	8	-	23.5	5650	87	13
			13	0.45	22	1.05	4	6	0	1.2	0.17	50	14.5	8	-	33	7900	56	44
			13	0.45	22	1.55	4	6	0	1.2	0.17	50	14.5	8	6	36.5	8750	33	67
Aug 18	37	67	13	0.45	22	0.9	6	6	0	1.5	0.18	20	14.5	8	-	23.5	8450	81	19
			13	0.45	22	1.05	6	6	0	1.5	0.20	20	14.5	8	-	27	9700	54	46
			13	0.45	22	1.55	6	6	0	1.5	0.20	20	14.5	8	-	29	10,550	39	61
Aug 7	32	68	13	0.45	22	0.9	6	6	0	1.2	0.23	100	14.5	8	-	26.5	9550	82	18
			13	0.45	22	1.05	6	6	0	1.2	0.23	100	14.5	8	-	34	12,250	49	51
			13	0.45	22	1.55	6	6	0	1.2	0.23	100	14.5	8	-	34	12,250	34	66

* Natural

APPENDIX 20

MOE 08-114 6-74

APPENDIX 21

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Oct 18	S-26	54	12	0.45	20	0.9	6	15	0	7	0.18	20	8	8	-	8.7	3150	79	21
			13	0.45	21	1.0	6	15	0	7	0.18	20	8	8	-	10.0	3600	54	46
			12	0.45	20	1.55	6	15	0	7	0.18	20	8	8	-	9.5	3400	33	67
Oct 20	S-28	48	12	0.45	20	0.9	6	15	0	4.5	0.15	20	14.5	8	8	8.8	3150	76	24
			13	0.45	21	1.0	6	15	0	4.5	0.15	20	14.5	5.5	5.5	6.2	2250	49	51
			12	0.45	20	1.55	6	15	0	4.5	0.20	20	14.5	4.8	4.8	6.0	2150	31	69
Oct 17	S-24	54	12	0.45	20	0.9	6	15	0	19	0.2	20	14.5	5.6	5.6	5.8	2100	78	22
			13	0.45	21	1.0	6	15	0	19	0.21	20	14.5	4.0	4.0	5.2	1850	56	44
			12	0.45	20	1.55	6	15	0	19	0.25	20	14.5	3.0	3.0	3.6	1300	33	67
Oct 17	S-25	54	12	0.45	20	0.9	6	15	0	18	0.19	20	18	4.2	4.2	4.5	1600	69	31
			13	0.45	21	1.0	6	15	0	18	0.19	20	18	3.6	3.6	4.2	1500	51	49
			12	0.45	20	1.55	6	15	0	18	0.23	20	18	2.5	2.5	2.8	1000	40	60

* Natural

APPENDIX 21

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APPENDIX 22

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals Alum ppm	Chemicals Poly ppm	Turbidity Raw FTU *	Turbidity Eff. FTU	Flocculation G Sec^{-1}	Flocculation Time min.	Head Loss Ft. Final	Head Loss Ft. Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution Coal %	Head Loss Distribution Sand %
Nov 2	56	55	13	0.45	22	0.8	4	12	0	13	0.16	20	4.5	8	-	13.4	3200	90	10
			13	0.45	22	1.05	4	12	0	13	0.16	20	4.5	8	-	16.8	4050	59	41
			13	0.45	22	1.55	4	12	0	13	0.16	20	4.5	8	-	15.5	3700	51	49
Oct 29	53	55	13	0.45	22	0.9	4	12	0	16	0.14	20	14.5	8	-	16.0	3850	78	22
			13	0.45	22	1.05	4	12	0	16	0.15	20	14.5	6	6	14.5	3500	59	41
			13	0.45	22	1.55	4	12	0	16	0.13	20	14.5	6	6	13.5	3250	49	51
Nov 5	58	53	13	0.45	22	0.9	4	12	0	15	0.16	20	28	7	7	14.0	3350	81	19
			13	0.45	22	1.05	4	12	0	15	0.17	20	28	4.7	4.7	11.5	2750	58	42
			13	0.45	22	1.55	4	12	0	15	0.16	20	28	4.5	4.5	10.0	2400	39	63

* Turbidity added to raw

APPENDIX 22

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APPENDIX 23

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Nov 3	57	55	13	0.45	22	0.9	4	12	0	14	0.16	300	4.5	8	-	13.0	3100	86	14
			13	0.45	22	1.05	4	12	0	14	0.16	300	4.5	7.5	7.5	17.3	4150	62	38
			13	0.45	22	1.55	4	12	0	14	0.16	300	4.5	7.2	7.2	15.5	3700	37	63
Oct 31	55	55	13	0.45	22	0.9	4	12	0	14	0.14	300	14.5	7.3	7.3	17.0	4080	78	22
			13	0.45	22	1.05	4	12	0	14	0.15	300	14.5	4.5	4.5	13.0	3120	56	44
			13	0.45	22	1.55	4	12	0	14	0.15	300	14.5	4.5	4.5	11.5	2760	34	66
Nov 7	60	50	13	0.45	22	0.9	4	12	0	15	0.14	300	28	6	6	13.0	3100	79	21
			13	0.45	22	1.05	4	12	0	15	0.14	300	28	3.6	3.6	12.0	2900	56	44
			13	0.45	22	1.55	4	12	0	15	0.14	300	28	3.7	3.7	9.5	2300	29	71

* Turbidity added to raw

APPENDIX 23

APPENDIX 24 DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Jan 31	64	33	13	0.45	22	0.9	4	12	0	11	0.20	20	4.5	8	-	18	4300	76	24
			13	0.45	22	1.05	4	12	0	11	0.20	20	4.5	6.2	6.2	17.3	4150	59	41
			13	0.45	22	1.55	4	12	0	11	0.20	20	4.5	6.3	6.3	15.3	3650	36	64
Jan 28	61	33	13	0.45	22	0.9	4	12	0	14	0.23	20	14.5	5.8	5.8	15.0	3600	71	29
			13	0.45	22	1.05	4	12	0	14	0.20	20	14.5	4.3	4.3	13.5	3250	57	43
			13	0.45	22	1.55	4	12	0	14	0.23	20	14.5	4.3	4.3	11.8	2850	37	63
Jan 30	63	33	13	0.45	22	0.9	4	12	0	13	0.20	20	28	4.2	4.2	10.5	2500	69	31
			13	0.45	22	1.05	4	12	0	13	0.20	20	28	2.8	2.8	9.5	2300	56	44
			13	0.45	22	1.55	4	12	0	13	0.20	20	28	3.0	3.0	8.0	1900	35	65
Feb 4	65	33	13	0.45	22	0.9	4	12	0	14	0.20	20	4.5	7.4	7.4	17.7	4250	73	27
			13	0.45	22	1.05	4	12	0	14	0.20	20	4.5	5.5	5.5	15.0	3600	57	43
			13	0.45	22	1.55	4	12	0	14	0.20	20	4.5	5.4	5.4	13.3	3200	32	68
Feb 5	66	33	13	0.45	22	0.9	4	12	0	14	0.18	20	28	4.0	4.0	11.0	2650	72	28
			13	0.45	22	1.05	4	12	0	14	0.20	20	28	3.1	3.1	9.5	2300	49	51
			13	0.45	22	1.55	4	12	0	14	0.20	20	28	3.1	3.1	7.8	1900	31	69

* turbidity added to raw

APPENDIX 25

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals Alum ppm	Poly ppm	Turbidity Raw FTU *	Eff. FTU	Flocculation G Sec^{-1}	Time min.	Head Loss Ft. Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution Coal %	Sand %
Feb 15	T-1	37	11	0.45	16	1.0	4	10	0.12	10	0.35	20	18	8	-	28.5	6850	58	42
			12	0.45	16	1.2	4	10	0.12	10	0.35	20	18	8	-	25.5	6100	52	48
			12	0.45	16	1.4	4	10	0.12	10	0.4	20	18	8	-	31	7450	50	50
			16	0.45	20	1.7	4	10	0.12	10	0.35	20	18	8	-	26	6250	22	78
Feb 17	T-2	36.5	11	0.45	16	1.0	4	25	0.12	10	0.05	20	18	6	6	10.5	2500	64	36
			12	0.45	16	1.2	4	25	0.12	10	0.05	20	18	6	6	10	2400	54	46
			12	0.45	16	1.4	4	25	0.12	10	0.05	20	18	5.0	5.0	11	2650	60	40
			16	0.45	20	1.7	4	25	0.12	10	0.05	20	18	5.5	5.5	11	2650	39	61
Feb 22	T-3	35.5	11	0.45	16	1.0	4	10	0.12	25	0.4	20	18	8	-	21	5050	59	41
			12	0.45	16	1.2	4	10	0.12	25	0.4	20	18	8	-	22	5300	58	42
			12	0.45	16	1.4	4	10	0.12	25	0.45	20	18	8	-	26	6250	55	45
			16	0.45	20	1.7	4	10	0.12	25	0.4	20	18	8	-	26	6250	28	72
Feb 29	T-4	38	11	0.45	16	1.0	4	10	0	25	0.40	20	18	4.5	4.5	14	3350	57	43
			12	0.45	16	1.2	4	10	0	25	0.35	20	18	4.5	4.5	16	3850	38	62
			12	0.45	16	1.4	4	10	0	25	0.45	20	18	4.0	4.0	12.5	3000	53	47
			16	0.45	20	1.7	4	10	0.110	25	0.35	20	18	8	-	20	4800	38	62

* turbidity added to raw

APPENDIX 26

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft^2	Chemicals: Alum ppm	Poly ppm **	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft^2	Head Loss Distribution: Coal %	Sand %
Mar 2	T-5	37.5	11	0.45	16	1.0	4	15	0.1	50	0.5	20	18	5	5	14	3350	55	45
			12	0.45	16	1.2	4	15	0.1	50	0.4	20	18	5	5	12	2900	37	63
			12	0.45	16	1.4	4	15	0.1	50	0.5	20	18	3.8	3.8	13	3100	47	53
			16	0.45	20	1.7	4	15	0.1	50	0.5	20	18	6	6	16	3850	29	71
Mar 28	T-6	37	12	0.45	16	1.0	2	10	0	10	0.3	20	42	4.5	4.5	50	6000	61	39
			12	0.45	16	1.2	2	10	0	10	0.3	20	42	4.5	4.5	56	6700	55	45
			12	0.45	16	1.4	2	10	0	10	0.3	20	42	4.2	4.2	58	6950	57	43
			12	0.45	18	1.55	2	10	0	10	0.3	20	42	5.5	5.5	60	7200	42	58
~~Apr 3~~	~~T-7~~	~~37~~	~~12~~	~~0.45~~	~~16~~	~~1.0~~	~~2~~	~~13~~	~~0.11~~	~~10~~	~~0.25~~	~~20~~	~~42~~	~~8~~	~~-~~	~~56~~	~~6700~~	~~82~~	~~18~~
			12	0.45	16	1.2	2	13	0.11	10	0.25	20	42	8	-	62	7450	70	30
			12	0.45	16	1.4	2	13	0.11	10	0.25	20	42	8	-	78	9350	70	30
			12	0.45	18	1.55	2	13	0.11	10	0.25	20	42	8	-	68	8150	67	33
Apr 4	T-8	37	12	0.45	16	1.0	6	10	0.10	4	0.3	20	18	8	-	12.5	4500	64	36
			12	0.45	16	1.2	6	10	0.10	4	0.3	20	18	8	-	13.1	4700	52	48
			12	0.45	18	1.55	8	10	0.10	4	0.3	20	18	8	-	11.2	5350	40	60

* Turbidity added to raw
** Separan NP10

APPENDIX 26

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Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU +	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Feb 4	65	33	13	0.45	22	0.9	4	12	0	14	0.20	20	4.5	7.4	7.4	17.7	4250	76	24
			13	0.45	22	1.05	4	12	0	14	0.20	20	4.5	5.5	5.5	15.0	3600	57	43
			13	0.45	22	1.55	4	12	0	14	0.20	20	4.5	5.4	5.4	13.3	3200	32	68
Feb 5	66	33	13	0.45	22	0.9	4	12	0	14	0.18	20	28	4	4	11.0	2650	73	27
			13	0.45	22	1.05	4	12	0	14	0.20	20	28	3.1	3.1	9.5	2300	49	51
			13	0.45	22	1.55	4	12	0	14	0.20	20	28	3.1	3.1	7.8	1900	31	69
Feb 6	67	33	13	0.45	22	0.9	4	19	0.105*	32	0.23	20	28	7.0	7.0	9.3	2250	76	24
			13	0.45	22	1.05	4	19	0.110*	32	0.23	20	28	5.5	5.5	8.8	2100	55	45
			13	0.45	22	1.55	4	19	0.110*	32	0.23	20	28	5.4	5.4	7.5	1800	32	68
Feb 7	68	33	13	0.45	22	0.9	4	18	0.105**	30	0.19	20	28	8	-	3.0	700	96	4
			13	0.45	22	1.05	4	10	0.105**	31	0.21	20	28	8	-	4.4	1050	94	6
			13	0.45	22	1.55	4	18	0.105**	31	0.19	20	28	8	-	5.7	1350	94	6
Feb 8	69	33	13	0.45	22	0.9	4	18	0.100***	31	0.16	20	28	8+	-	10.2	2450	68	32
			13	0.45	22	1.05	4	18	0.100***	31	0.18	20	28	5.6	5.6	10.0	2400	53	47
			13	0.45	22	1.55	4	18	0.100***	31	0.16	20	28	6.1	6.1	10.0	2400	43	57

*Separan NP10   ** Purifloc N20   ***Nalcolyte 8171   + Turbidity added to raw

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APPENDIX 28 DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff. mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU *	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
Jan 28	61	33	13	0.45	22	0.9	4	12	0	14	0.23	20	14.5	5.8	5.8	15.0	3600	71	29
			13	0.45	22	1.05	4	12	0	14	0.20	20	14.5	4.3	4.3	13.5	3250	57	43
			13	0.45	22	1.55	4	12	0	14	0.23	20	14.5	4.3	4.3	11.8	2850	37	63
Jan 29	62	33	13	0.45	22	0.9	4	12	0	14	0.22	300	14.5	6.0	6.0	10.8	2600	77	23
			13	0.45	22	1.05	4	12	0	14	0.22	300	14.5	4.3	4.3	9	2150	54	46
			13	0.45	22	1.55	4	12	0	14	0.23	300	14.5	4.3	4.3	7.5	1800	38	62
Jan 30	63	33	13	0.45	22	0.9	4	12	0	13	0.20	20	28	4.2	4.2	10.5	2500	69	31
			13	0.45	22	1.05	4	12	0	13	0.20	20	28	2.8	2.8	9.5	2300	56	44
			13	0.45	22	1.55	4	12	0	13	0.20	20	28	3	3	8.0	1900	35	65
Jan 31	64	33	13	0.45	22	0.9	4	12	0	11	0.20	20	4.5	8+	-	18	4300	76	24
			13	0.45	22	1.05	4	12	0	11	0.20	20	28	6.2	6.2	17.3	4150	59	41
			13	0.45	22	1.55	4	12	0	11	0.20	20	4.5	6.3	6.3	15.3	3650	36	64

* turbidity added to raw

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APPENDIX 29

DIRECT FILTRATION

Date	Run #	Temp °F	Filter Media: Sand Depth in.	Sand Eff mm	Coal Depth in.	Coal Eff mm	Filtration Rate IGPM/ft²	Chemicals: Alum ppm	Poly ppm	Turbidity: Raw FTU	Eff. FTU	Flocculation: G Sec^{-1}	Time min.	Head Loss Ft.: Final	Break Through	Run Length Hours	Total Filtered Imp. Gal/ft²	Head Loss Distribution: Coal %	Sand %
9-11-71	H-13	42	12	0.45	18	1.0	2.55 AV	12	0.05	18	0.10	20	8	8.0	-	23	3500	93	7
10-11-71	H-12	42	12	0.45	18	1.0	2.6	12	0.05	20	0.13	20	8	8.0	-	18	2800	89	11
11-11-71	H-13	42	12	0.45	17	2.0	2.9 AV	12	0.05	18	0.10	20	8	8.0	-	25	4350	29	71
9-11-71	H-11	42	12	0.45	17	2.0	2.6	12	0.05	18	0.10	20	8	8.0	-	25	3900	67	23
17-7-72	S-6	52	13	0.45	23	1.0	4.25 AV	8	0	1.5	0.17	20	14.5	7.5	-	31.5	8050	57	43
14-7-72	S-5	55	13	0.45	23	1.0	4.0	8	0	1.7	0.20	20	14.5	8.0	-	33.0	7900	59	41
18-7-72	S-7	52	12	0.45	20	1.55	7.4 AV	20	0.2	1.5	0.17	20	14.5	7.0	-	10.5	4650	75	25
2-8-72	S-8	62	12	0.45	20	1.55	7.4	7	0.2	1.5	0.13	20	14.5	8.0	-	9.0	4000	75	25

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